



EDWARD VICTOR and
MARJORIE S. LERNER

**READINGS in SCIENCE EDUCATION
for the ELEMENTARY SCHOOL**

SECOND EDITION

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Readings in
Science Education
for the
Elementary
School



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PREFACE

This revised edition continues to be concerned not only with current thinking, practices, and research in elementary science but with innovations and changes as well. Consequently, approximately one third of the articles in the first edition have now been replaced with articles that are more timely or have greater significance. Thus the book maintains a balance between the older key articles and the newer articles that describe both present and future patterns of thinking in elementary science.

The book is again designed to serve two purposes. First, the current widespread activity in elementary science is rapidly producing new developments in several directions. So much is being written today about issues, problems, practices, current thinking, innovations, and trends in elementary science that it is difficult to read all the literature, digest it, and separate the wheat from the chaff. A book of selected readings makes it possible to include under one cover the key articles that will give a clear picture of what is happening in elementary science today.

Second, instructors of methods courses and of graduate seminars in elementary science often distribute reading lists and require outside reading. With today's large enrollments in our colleges and universities, the assignment of articles to be read places a heavy burden on the students and on the already overtaxed library facilities. The demand for periodicals that contain these articles becomes great, and the students must wait their turn to obtain them. A book of readings eliminates this problem and makes the articles readily accessible to each student.

A book of readings in elementary science has several worthwhile features:

1. It can familiarize the student with the professional journals that are concerned with education and the teaching of science.
2. It can introduce the student to a comprehensive sample of the best thinking in elementary science today.
3. It can acquaint the student with points of view of other persons besides the instructor and the author of the textbook used in the course.

4. It can present a number of different positions that have been taken on controversial topics.
5. It can be used either as a basic text or as a supplementary text.
6. It can be especially helpful in late afternoon, evening, Saturday, extension, or summer courses, where the in-service teachers who take the course are hard pressed to find enough time to locate the articles in the campus library and to read them.

The book continues to be organized into eight sections. The first five sections deal with the role of science in the elementary school, the objectives of elementary science, planning and organizing the science program, methods and innovations in teaching elementary science, evaluation of both science learning and the science program, and the need for adequate materials and facilities for elementary science.

Section 6 takes up the pre-service and in-service science training of elementary teachers, and shows how the school administrator, the state, and the federal government can play a leadership role in improving science education in the schools. It describes the need for science supervision and lists the qualifications and functions of the science supervisor. Section 7 presents in detail the thinking of scientists, science educators, and psychologists who are concerned with inquiry and process in the learning of science. Section 8 describes the current progress and evaluation of the existing major curriculum study projects that are developing improved elementary science programs.

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E. V.
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THE ROLE OF SCIENCE IN THE ELEMENTARY SCHOOL

INTRODUCTION

Science is a comparative newcomer to the elementary school curriculum, although its roots can be traced back a hundred years or more. In the latter part of the nineteenth century, children were introduced to object study, where both animate and inanimate objects were observed and described. In the early part of the twentieth century, nature study became very popular in many elementary schools.

However, there is general agreement that elementary science really began around 1930 with the growth of a movement to teach all areas of science in the elementary school and to make science a dynamic and integral part of the elementary school curriculum. This movement grew rather slowly, but steadily, gaining support throughout the country.

In the past fifteen years two phenomena have taken place which have given the movement tremendous impetus and rapid growth. First, the vast and almost explosive scientific and technological revolution in our midst has produced a fantastic growth of scientific knowledge in all areas of science, and this wealth of knowledge is now exerting an effect on all of science education. Second, the impact of the satellite Sputnik succeeded in arousing the concern of scientists, science educators, teachers, administrators, the public in general, and the government in the kind and amount of science being taught and learned in our schools. As a result, there is widespread interest and activity in elementary (as well as secondary) science today. There is also unanimous agreement on a strong K-12 science sequence in our schools, and on a well-developed science program in the elementary school as part of this sequence.

An effective science program can play an important role in the elementary school. It can add to the child's store of knowledge about himself, his environment, and his world. It can give the child an insight into the structure of science, enabling the child to learn key concepts, conceptual schemes, and their relationships to each other. It can help the child live successfully in a changing world by showing that our universe is based upon change. Learning about change in science, and how to cope

with change, will help the child react more intelligently to the changes he may expect in his future.

Elementary science can play an important role in helping the child learn the nature of scientific inquiry and the key operations, or processes, of science and of the scientist. A program based on inquiry and process will encourage real learning to take place, not the memorization of facts. The child will be encouraged to think critically and to develop scientific attitudes and skills.

The very nature of an effective science program makes it possible to offer a wide variety of learning activities and experiences which can provide for the individual differences in ability, interest, and need that all children have. The science program lends itself very well to individual learning, making it possible for each child to develop to the limit of his capacity.

Finally, the science program can be correlated very effectively with other programs in the elementary school curriculum. Learning is always more effective when all phases of the curriculum are integrated. There are many opportunities in the elementary school to correlate science with mathematics, language arts, social studies, and the creative arts.

SCIENCE FOR CHILDREN—WHY?*

Katherine E. Hill

Katherine E. Hill takes issue with the stress that some educators place on the idea that boys and girls should learn skills and concepts of science to give them insights into how scientists work or to have them become little scientists. Rather, Dr. Hill believes that the purpose of science in the elementary school is to assist children to build skills and concepts which will enable them to cope more effectively with the objects, forces, and events which comprise their environment. For those responsible for developing curriculum for our elementary schools, their commitment must be in terms of children, not in terms of science.

Assisting children to learn is both a privilege and a challenge. The privilege is in watching a child's expression of bafflement change to one of comprehension, in finding a child so involved in reading or observing or some other endeavor that it is difficult to gain his attention, in hearing a child enthusiastically sharing a new idea with his friend. The challenge comes in grappling with the problems of how to assist children in their learning and of what the content of the learning shall be.

Research in the teaching of science in the elementary schools has provided considerable information, much of it in terms of what children are capable of learning. We know, for example, that boys and girls can learn to observe, to classify, to measure, to inquire, to infer, to hypothesize. Further, we know that they can begin to acquire each of these skills at an early age and can improve in their understanding and use of the skills as they grow older.

Designing and field-testing units focused on building concepts related to such topics as microscopic organisms, cells, worms, stars, systems, plant germination, action and reaction, magnetism, and motion has provided additional information. We know that children can learn countless concepts about natural phenomena.

In short, recent research makes it clear that children are capable of learning a great deal. Knowing *how* to assist children in their learning is perhaps even more useful. But such knowledge does not solve the problem of *what* children shall learn.

* REPRINTED FROM *Science and Children*, Vol. 3, No. 8, May 1966, pp. 11-12. Copyright, 1966, by the National Science Teachers Association, Washington, D.C. Reprinted by permission of the author and the publisher. Dr. Hill is Professor of Education at New York University.

Perhaps the answer to what shall be taught in science lies in a consideration of the question, "Science for children—why?" Some educators stress that the reason boys and girls should learn skills and concepts of science is to give them insights into how scientists work, perhaps even to produce "little scientists."

Does such an attitude bring education at the elementary school level dangerously close to pushing children toward a vocational choice before they are twelve years of age? Is it a defensible goal to lead children to understand how scientists work any more than how physicians, artists, teachers, musicians, bakers, carpenters, steam shovel operators, secretaries, authors, generals, politicians, or hundreds of other people work?

The purpose of learning in the elementary schools is not that of learning how to perform as a scientist or as a worker in any other area. Rather, the purpose is to assist boys and girls to build skills and concepts which will enable them to cope more effectively this year, this month, this day of their lives with the objects, forces, and events which comprise their environment. The science skills—observation, measurement, classification, inference, and so on—can be translated into immediate behavior by the child as he attempts to understand the phenomena of science encountered in his environment.

However, boys and girls must also realize that these skills under consideration are not the exclusive property of science. Observation is used by the child who paints his impressions of a landscape. Inferences are drawn by the child who considers the work people do and the rewards of their work. Surely, if many of the skills needed in science are needed in other curriculum areas, it is not wise to center a science curriculum on the development of skills.

Skills must be built as one uses the subject matter of a discipline. A child's ability to classify is developed as he considers land forms, as shown on maps being used in social studies, uses crayons or paint in art, and studies the structure of animals in science.

The curriculum worker is faced, then, with the problem of deciding which science concepts shall be developed. Having elementary school children take courses in botany, chemistry, or any of the other science disciplines was discarded long ago. So was the idea of developing concepts related to topics chosen solely on some such opportunistic basis as children's interest or prominence in the news.

More and more, children are being considered as growing, developing individuals who are challenged by meeting closely related science phenomena day after day. For this reason, a defensible method for selecting content for the science curriculum is: (1) to determine the basic ideas, patterns, themes, or conceptual schemes which are useful in interpreting natural phenomena and (2) to select those concepts which give promise of building optimum understandings of the basic ideas which can be employed throughout a lifetime.

There is no final agreement among educators, at this point, as to which are the basic patterns or conceptual schemes most useful in this respect. However, it is interesting to note the similarities in the patterns suggested from several sources.

Gerald S. Craig¹ suggests the following large patterns as guidelines for teaching and learning: (1) The Universe Is Very Large Space, (2) The Earth Is Very Old—Time, (3) The Universe Is Constantly Changing—Change, (4) Life Is Adapted to the Environment—Adaptation, (5) There Are Great Variations in the Universe—Variety, (6) The Interdependence of Living Things—Interrelationships, and (7) The Interaction of Forces—Equilibrium and Balance.

Paul Brandwein² suggests these conceptual schemes as basic ideas: (1) Under ordinary conditions, matter can be changed but not annihilated or created; (2) Under ordinary conditions, energy can be changed or exchanged but not annihilated; (3) There is an interchange of materials and energy between living things and their environment; (4) The organism is a product of its heredity and environment; (5) The universe, and its component bodies are constantly changing; and (6) Living things have changed over the years.

In abbreviated form, the conceptual schemes proposed in the National Science Teachers Association publication, *Theory Into Action*,³ are as follows: (1) All matter is composed of units called fundamental particles; under certain conditions these particles can be transformed into energy and vice versa; (2) Matter exists in the form of units which can be classified into hierarchies of organizational levels; (3) The behavior of matter in the universe can be described on a statistical basis; (4) Units of matter interact; (5) All units of matter tend toward equilibrium states. In the process of attaining equilibrium, energy transformations or matter transformations or matter-energy transformations occur; (6) One of the forms of energy is the motion of units of matter; (7) All matter exists in time and space and, since interactions occur among its units, matter is subject in some degree to change with time.

A consideration of these basic patterns and conceptual schemes shows us, at once, that sufficient experiences must be provided each year to allow children to interact in depth with phenomena representative of the several aspects of natural environment. Such experiences

¹ Gerald S. Craig. *Science for the Elementary-School Teacher* Ginn and Company, Boston, Massachusetts. 1964. p. 93-101.

² Paul F. Brandwein *The Teaching of Science Elements in a Strategy for Teaching Science in the Elementary School*. Harvard University Press, Cambridge, Massachusetts. 1962. p. 132-136.

³ Paul DeHart Hurd. NSTA Curriculum Committee and the Conference on Science Concepts. *Theory Into Action* National Science Teachers Association, Washington, D. C. 1964. p. 20.

might be thought of as those related to: (1) living things; (2) matter, energy, and motion; (3) Earth; and (4) Earth in space. Planning for such a variety of experiences annually is essential if all the patterns or conceptual schemes are to be conceived as operating throughout the natural environment.

Science for children—why? The answer lies in the hands of those responsible for developing curriculum in our elementary schools. Their commitment must be in terms of children, not in terms of science. They know that boys and girls need assistance in the continuous process of building those abilities needed in interpreting natural phenomena in the environment. If this is the answer to *why* science in the elementary school, then this is also the criterion to be employed in determining *what* skills and concepts of science shall be taught.

EDUCATION AND THE SPIRIT OF SCIENCE*

Educational Policies Commission

The following article is an excerpt of a larger report of the Educational Policies Commission of the National Education Association and the American Association of School Administrators. The Commission believes that the following seven basic values underlie science: (1) longing to know and to understand, (2) questioning of all things, (3) search for data and their meaning, (4) demand for verification, (5) respect for logic, (6) consideration of premises, and (7) consideration of consequences. The Commission states that to communicate the Spirit of Science and to develop people's capacity to use its values should be among the principal goals of education.

The schools should help to realize the great opportunities which the development of science has made apparent in the world. They can do this by promoting understanding of the values on which science is everywhere based. Although no particular scientist may fully exemplify all these

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values, they characterize the enterprise of science as a whole. We believe that the following values underlie science.

1. Longing to know and to understand.
2. Questioning of all things.
3. Search for data and their meaning.
4. Demand for verification.
5. Respect for logic.
6. Consideration of premises.
7. Consideration of consequences.

These values are not stated the way more traditional values are stated. They do not contain some of the traditional value words, such as *love*, *honesty*, *beauty*, or *patriotism*. But neither are they necessarily in conflict with traditional values. Like all values, they are guidelines for belief and hence, for action. Some of them merely define traditional values, for example, the demand for verification is nothing other than an approach to, and a profound respect for, honesty. Some of them undergird, and almost make inevitable, values which are often expressed as self-evident truths, for example, an awareness of consequences makes love of one's children and responsibility to one's neighbors essential. And, like other sets of values, they have the defect that neither individually nor jointly do they provide a fully adequate guide to action, in many concrete human situations, various values, all cherished, are involved, and the choice of action involves an ethical compromise. The values of the spirit of science express the belief that the compromise is likely to be better if based on thoughtful choice; in this respect they differ from those value systems which hesitate to submit all problems to reason. Perhaps they differ from some other sets of values in the degree of reliance they place on the individual. Instead of insisting on his acceptance of certain values favored by men or groups allegedly wiser than he, the spirit of science insists that he make up his own mind. In this, the values of science are the most complete expression of one of the deepest of humane values—the belief in human dignity.

By their very nature, these values cannot be acquired through indoctrination. For the spirit of certainty upon which indoctrination rests is contradictory to each of them. Dictatorships do not make progress in knowledge and capability in those areas in which they insist that the truth is already known. Consequently these values, unlike indoctrinated values, are part and parcel of any true education. These are characteristic not only of what is commonly called science but, more basically, of rational thought—and that applies not only in science—but in every area of life. What is being advocated here is not the production of more physicists, biologists, or mathematicians, but rather the development of persons whose approach to life as a whole is that of a person who thinks—a rational person. The characteristics of this mode of thought merit consideration in greater detail.

1. *Longing to Know and to Understand*

The spirit of science is, at bottom, a longing to understand. It seeks to understand because it accepts knowledge as desirable in itself. It expresses its curiosity endlessly, recognizing that questions are infinite, answers finite. The events which surround an inquiring person pose for him the fundamental problems of why and how. He deems it a worthy investment of himself and of mankind to become mobilized in the search for answers.

2. *Questioning of All Things*

There is no perfect knowledge and no perfect knower. Certainty, as a concept, is replaced by probability. All conclusions and decisions are more or less suspect; science rides on a preference for the less over the more.

If certainty is illusory, it is partly because men cannot be fully objective. Some tinge of the observer must color any observation. If men cannot eliminate this influence, they can at least take it into account. The pursuit of the highest probability of accuracy in conclusions calls on an observer to be aware of the full range of experiences within which he operates, including his own subjective, intuitive, aesthetic, and nonrational responses. These responses have their own uses and compose also part of the reality to which the spirit of science extends. They could not be eliminated even if that were desirable. A scientific thinker does not attempt to snuff them out; he tries rather to be aware of them and to understand which of them are helpful and which are harmful, which are harmless, and which irrelevant.

Here is a prime source of that attitude of modesty and humility which characterizes the general posture of the seeker after knowledge. Conscious of the uncertainties with which he deals, he must nevertheless reach some sorts of operating conclusions. He must, from time to time, act or decide, always with incomplete evidence, by incomplete intellectual devices, with even incomplete means of reading results. Incompleteness rules science, producing a universal spirit of tentativeness and inhibiting the development of that ferocious intolerance so often revealed when supposedly definitive beliefs are challenged.

Since scientific knowledge is tentative, all propositions are subject to being revised or discarded. Reluctance to discard beliefs is one of the most difficult problems of rational thought for two reasons: (1) A thinker himself treasures certain concepts, values, or "self-evident" truths which have served him in his own life; these he challenges only with difficulty. (2) A thinker usually depends on support from the larger community in which he works, and that community may be unwilling to examine certain values—for example, those of religious or national traditions—which his work may call into question. He may thus be confronted with a conflict between loyalty to the basic values of the scientific spirit and the practical steps necessary to advance it.

In spite of these difficulties, a thinker feels compelled to insist that the

range of his curiosity cannot accept limits imposed by external authority. He examines external authority as well. There is no sanctuary for ideas.

3. Search for Data and Their Meaning

The longing to know is the motivation for learning; data and generalizations are the forms which knowledge takes. Generalizations are induced from discrete bits of information gathered through observation conducted as accurately as the circumstances permit.

Much of science consists of the acquisition and ordering of data. But data taken by themselves normally have little meaning. The principal contribution of scholarship to an understanding of the world is found, not in such data, but in theories which explain phenomena. Scientists often refer to these theories or insights which interrelate data and give them meaning as *conceptual schemes*. The evolution of these conceptual schemes is an intuitive, highly creative process. It involves seeing connections and meanings others have not seen. Here is the place for intuition and creativity in science and in all other modes of thinking which seek the same values. The process of creating new integrations implies flexibility, originality, breadth and fluency of mind, and freedom to skip from one frame of reference to another sensing new relationships and hidden meanings.

4. Demand for Verification

Implicit in the concept of the tentativeness of knowledge and of conceptual schemes is the concept of test. Knowledge is, at best, hypothetical, and the statement of a hypothesis suggests that it is subject to test. A thinker, therefore, consciously seeks to find ways to expose the results of his thinking to test or experiment and to the play of as many other minds as possible.

Conceptual schemes may be arrived at both inductively and deductively. Unless they can be confronted with the results of empirical test, however, they are little likely to gain widespread support. The scientific spirit is therefore predisposed to the search for such test as the basis for favorable evaluation.

The search for a testing situation is itself a highly creative act. A scientist does not merely permit the evaluation of his conceptual schemes; he actively seeks it. He values the positive and imaginative creation of situations which test hypotheses, suggest new ones, promote exploration, and give expression to the spirit of excitement and adventure which suffuses the scientific enterprise. Furthermore, the creation of new means of verification may itself be a significant scientific advance.

5. Respect for Logic

Logic is the science of valid inference. Logical systems constitute agreed

bases by which the validity of inferences may be judged. There are a number of such logical systems, and new ones are in constant process of growth. But all of them agree on the meaning of such basic concepts as consistency and contradiction.

Logic is used in connecting a thinker's concepts in a manner open to evaluation by other persons. A thinker judges the validity of inferences and deductions in terms of logic. But he recognizes also that no amount of logical consistency will make valid any inferences or deductions which proceed from inadequate or faulty premises. Mere logical consistency does not constitute an adequate appraisal of a concept, proposition, or idea. It is also necessary to ask whether the data being reviewed are relevant and necessary in the situation and whether the premises are both relevant and sufficient.

6. Consideration of Premises

A thinker is at the center of any situation involving knowledge. As he seeks knowledge or understanding in any situation, he recognizes that he must keep in mind not only the external questions which confront him, but also internal predispositions that shape his thoughts. As he applies and develops the values of science, he does so consciously, and tries to be sensitive to his own inadequacies in that effort.

There is a limit to fruitful inquiry into one's premises and assumptions. In this effort, too, certainty is unobtainable. But, in choosing to act or conclude, a thinker does not rest assured that he has reached the firm bedrock of faith. Rather, he recognizes that he has reached the present limitations of his abilities. Humility is required, and fanaticism excluded, by the spirit of science.

7. Consideration of Consequences

To hold to a value or to decide upon an action without awareness of its implications or its consequences is to believe or act in partial ignorance. Awareness of implications can, like the rest of knowledge, at best be incomplete. But a rational person does not accept a value or decide upon an action without trying to be aware of its implications. He recognizes that he is, after all, part of the human race and that his decisions will have bearing on other persons and will be judged by other persons. He cannot, therefore, think of his single localized decision only, but must recognize that each conclusion or decision will reach a wider circle of influence. He must, then, think about implications and consequences, take them into consideration, and avoid actions whose backwash will be harmful. A sense of responsibility is inherent in honest thought.

This does not mean that the search for knowledge must lead only to happy results. But neither does any other value. The search for knowledge made the atomic bomb possible, but it led to that result only in the

service of other values—love of country and hatred of tyranny. One would be hard put to name a value whose results, in the light of all other cherished values, have always been exclusively good.

If a single word summarizes the various characteristics of the scientific spirit, it is *awareness*—awareness of the uncertainty of man's knowledge, awareness of the extent to which the self influences one's perceptions, awareness of the consequences of one's values and actions, awareness of the painstaking modes of thought which have enabled man gradually to develop his knowledge of the world. This awareness is the basic stuff of freedom; only insofar as a man is aware of the influences upon him can he filter them and become himself, and only insofar as he is aware of the problems and modes of knowing can he help himself and others to understand the world.

Here, then, is a group of values which schools can promote without doing violence to the dignity of the individual. Here are values which are not intended to be accepted on the basis of external authority. On the contrary, they are themselves frankly intended to be challenged. The school here envisioned would have failed in the case of any student who has never questioned the desirability of these values. It would have failed in the case of any student who has never compared the various bases which different men deem sufficient for knowing or for acting. The view of teaching as the indoctrination of superior knowledge and wisdom here gives way to a concept of teaching as promotion of the development of the learner from within.

In this way, schools can be profoundly concerned with values and ethics in a manner fully consistent with the democratic belief in the dignity of the individual and with the scientific belief that no one—the school included—knows the final answers.

What is advocated here is not a separation of science from other aspects of life but rather the understanding that the spirit of science applies to other facets of man's existence. It fuses with many kinds of thinking that men traditionally consider distinct from it.

The view that there is a necessary conflict between the scientific and the humanistic approaches to life is not valid. When science is isolated from the moral and spiritual aspects of life it can produce the monstrosities so often feared, just as the acceptance of values on the basis of emotion and without rigorous examination of their likely consequences has often produced abominations.

The values of which the spirit of science consists should permeate the educative process, serving as objectives of learning in every field, including the humanities and practical studies. These values can be learned in connection with any kind of intellectual activity. Indeed, all parts of the educational program should reflect the unity of life. For example, any subject can be so taught as to contribute to the student's tendency both to examine all concepts and to inquire into the social implications of the

questioning spirit. The thorough compartmentalization of subjects in a school is in conflict with human experience and the best interests of human development. The schools must continue to sensitize students to the aesthetic and ethical experience of civilization and should try to unify all these considerations.

It cannot be assumed that the addition of science courses to a curriculum would necessarily contribute to the achievement of these goals. Indeed, science can be so taught as to be irrelevant or even opposed to their achievement. Efforts to discourage challenges to traditional beliefs and attempts to indoctrinate are probably widespread in every school system, however advanced the content of science courses. What is needed is an education which turns the child's curiosity into a lifelong drive and which leads students to consider seriously the various possibilities of satisfying that curiosity and the many limitations on those possibilities.

Just as the values of the spirit of science can serve as educational goals in American schools, they can also serve to help orient the foreign operations of the United States government. It should be a direct aim of American foreign aid and technical assistance programs to help other nations to foster these values. This may not be an appropriate immediate objective for many countries, but without it as a long-range goal, a nation's intellectual, and hence other, resources cannot be satisfactorily developed. Two objections immediately arise. The first is related to the propriety of setting goals for other peoples. Certainly, to set goals for foreign peoples is not only contrary to the American sense of justice, it is also impossible to carry out, for the United States does not rule the countries which it aids. But in most cases the problem is not likely to arise in any more acute form than it does in economic development. All countries, however poorly endowed in mineral resources, have a vast and largely untapped potential in mental resources. Increasingly they are recognizing that their progress—as they define it—hinges on their success in developing the minds of their people. In particular, as noted earlier, all countries wish to foster their scientific development. They themselves realize that if they lack people who master the spirit of science, they will be dependent on the creative science of other countries. To countries that wish to foster individual freedom, the relationship between the values of the spirit of science and individual freedom is evident.

The second objection that arises is that little is known about how to promote learning of these seven values. The objection is valid, but inadequate. Little is known, too, about fostering the economic development of nations; but that has not kept nations from trying—or from succeeding to some extent. That goal has been deemed important enough to justify doing the best one can with inadequate knowledge. The goal here proposed is, in our opinion, also important enough to justify trying. Indeed, we think that economic development itself calls for the achievement of this goal. Furthermore, educators traditionally have

sought goals which they have known only imperfectly how to achieve. Among them are social responsibility, creativity, honesty, and patriotism. For these reasons, we do not regard the scantiness of knowledge of how to foster rationality as a sufficient argument against making the attempt. It is rather a challenge to do the best that can be done with present knowledge and to undertake the sorts of research that will enable mankind to do the job better.

Furthermore, these seven values of the scientific spirit are all quite specific educational goals. There is no reason to doubt that they can be sought and gradually promoted. Certainly the rewards for doing so might be immense.

Not only would solid progress in the direction of these educational goals yield immediate benefits such as improved standards of living and health, but also there might be found in these developments gains in ethical dimensions which have long eluded man. Although these values are those of science, and although science is often said to be neutral on questions of value, there are many ethical implications which flow from these scientific beliefs. The longing to know and the demand for verification imply honesty, reliability, and responsibility; every practitioner of science depends on the honesty of other scientists. Each realizes that this requirement also rests on him. The pursuit of truth is impeded by a lack of mutual trust and faith.

Implicit also in these values is a modesty or humility which contrasts with the boastful self-assurance of arbitrary authority. A man of science is suspicious of certainty. He insists that no concept, proposition, or belief is immune to examination and possible rejection. He is willing to challenge even the scientific approach as he understands it. Most of all, he is willing to see his own conclusions challenged. He recognizes his own failings and those of others. He knows that no observer, thinker, communicator, corroborator, or other human link in the scientific process is perfect.

It is often said that science is amoral. One may legitimately ask, however, whether the spirit of science does not have truly humane implications. What are the ethical implications of recognizing that all that is known is known by minds; or recognizing that there is no science—or art—except that which is carried by human beings; or recognizing that every human being has at least the potential of contributing to that which is known? Those who are conscious of the power of the human mind and of the vastness, if not infinity, of the fields for minds to conquer, can hardly avoid a profound longing for all minds to be developed.

Moreover, as noted above, a reluctance to accept ignorance as a basis for belief or action implies a responsibility to understand the premises and consequences of one's beliefs and actions. But to say that a sense of responsibility is inherent in the scientific spirit is not to say that all scientific thinkers will inevitably come to conclusions acceptable to most other people. Thus, there may be some dangers in a commitment to

individual freedom and in a true acceptance of the belief that no one knows the final answers. But there have been great dangers also in other commitments. The traditional morality has, after all, included such items as devotion to nation and the supposed unquestionability of certain knowledge; and acceptance of each has repeatedly occasioned misery to the world. Perhaps it would be no less safe to entrust the future to people who constantly ask "why," to people whose acceptance of the need for certain social rules derives from understanding rather than obedience, to people who doubt the finality of their own wisdom and of the wisdom of others, to people who try hard to understand the premises and implications of their values and decisions.

It cannot be guaranteed that a society which seeks the scientific spirit will avoid repetition of the inhumane acts with which history is replete. Religious wars have repeatedly been fought by men who professed belief in faiths devoted to peace. Science might be similarly distorted by scientists, but such distortion is neither required nor justified by scientific traditions. It arises, not from devotion to the spirit of science, but from failure to be guided by it.

The spread of science and technology may indeed carry seeds of a most hopeful future for man. Perhaps the most visible phenomena of international relations are nationalism, hatred, and violence. They account for the headlines, and their genuine significance cannot be denied. But there may be a deeper tide in world affairs, a tide too quiet to produce headlines but of overwhelming importance to the future of mankind. That tide is the development of a common commitment to a set of values which, in the hands of a very few persons in a very few countries over a very short period of years, has given man unprecedented powers to perceive, to understand, to predict, to control, and to act.

The profound changes men have wrought in the world by their uses of science and technology have been for better and for worse. But the spirit underlying science is a highly desirable spirit. It can enable entire peoples to use their minds with breadth and dignity and with striking benefit to their health and standard of living. It promotes individuality. It can strengthen man's efforts in behalf of world community, peace, and brotherhood. It develops a sense of one's power tempered by an awareness of the minute and tenuous nature of one's contributions. Insofar as an individual learns to live by the spirit of science, he shares in the liberation of mankind's intelligence and achieves an invigorating sense of participation in the spirit of the modern world. To communicate the spirit of science and to develop people's capacity to use its values should therefore be among the principal goals of education in our own and every other country.

THE LIBERAL EDUCATION VALUES OF SCIENCE*

Morris Kline

In this article Morris Kline describes how science contributes to the liberal education of the child. Three key components make up this liberal education: knowledge, a rational spirit, and an appreciation of esthetic and emotional values. The author also makes a strong plea for teaching the cultural values of science. In his discussion science is described as encompassing pure science, technology, and mathematics. He finds strong unity in these three fields, even though their immediate goals may be different.

A liberal education imparts the knowledge, beliefs, law, customs, and mores which our civilization possesses. However, it is not the purely factual knowledge but the significance of that knowledge that matters. The goal is wisdom. A liberal education also produces a state of mind. It trains the intellect by inculcating a critical attitude, independence of mind, open-mindedness or a mind open to change, a reasoned approach to problems, a willingness to look at facts either as a test of beliefs or as support for beliefs, and a sympathy for strange ideas. It imparts the ability to rise above one's age and to examine critically the presuppositions of one's age. I shall use the word rationalism to stand for all these qualities. Thus, in brief, a liberal education teaches rationalism. The third factor in a liberal education is an appreciation of the creations that satisfy emotional and esthetic needs. Art, music, religion, and literature are among the creations that cater to these needs. In discussing the liberal education values of science, I shall concentrate on those which can be taught to young people.

There is a unity of mathematics, science, and technology which is sufficiently strong that, for the purposes of this discussion, I shall use the word science to embrace all three fields. I am not recommending that we confuse the three. Their immediate goals are different; funds for basic research must be distinguished from funds for development; the individual

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temperament must play a role in the individual's choice of his own specialty.

Pure science to satisfy intellectual curiosity is not enough. Science is to be used, not for the narrow purpose of making money, but in behalf of mankind. Science is a river with two sources, the practical and the esthetic, and neither is nobler nor more fruitful than the other. If anything, technology is the fruit of science.

SCIENCE PROPER IS PART OF A LIBERAL EDUCATION

The knowledge which science offers is as much a part of our culture as literature and painting. That the two have become separated and that we speak of science and culture as though they were fields apart are the result of historic factors which I cannot take up here. But we should not allow ourselves to be confused or influenced by current misconceptions.

The knowledge that science offers is weighty and interesting knowledge. Our astronomy tells us the scheme by which we make sense of the grandest spectacle in nature. The phenomena of light and sound are with us almost at every moment, and surely we should like to know about such prevalent and necessary phenomena. Biology gives us knowledge of the structure of our bodies; and psychology, of our own drives, fears, anxieties, memory, and emotions. Science answers basic questions man raises about a world which is more immediate to him than foreign countries, ancient history, and even the government in Washington.

Science makes available practical knowledge. Science is man's weapon to cope with nature and the weaknesses in his own body. Science helps us to use the minerals of the earth, to improve agriculture and the husbandry of animals, and to fight diseases of the body. More generally put, science is the organization of our knowledge which enables us to command nature and the potential in nature.

But scientific knowledge *per se* is not by any means the be-all and end-all of the educational role of science—in fact, the values of science which transcend mere knowledge are more significant than the factual information.

A liberal education develops a state of mind which for brevity I have tried to describe by the word rational but which encompasses a critical outlook, a skeptical attitude, a willingness to face facts, the insistence on evidence to back up beliefs or assertions, an ability to rise above the prejudices of the herd and idols of the tribe, a reliance upon the mind, independence of thought, open-mindedness, weighing of evidence and other qualities I mentioned earlier. If I were to single out the greatest contribution of science to culture I would emphasize the inculcation of this rational spirit.

Each of these elements of the rational spirit can be learned through science education; for example:

Science teaches us how to think. There are various methodologies of thinking in science. The experimental method teaches how to look for a cause-and-effect sequence by isolating the cause and effect. Numerous possible causes of a given effect may be present, and these must be considered and eliminated. The classificatory method of the biological sciences does institute order in thousands of varieties of plant and animal life and permits inferences to be made about them. For example, if oxygen is necessary to sustain life in animals, fish must secure oxygen; and we are directed to look for and into that mechanism. The mathematical sciences have been extolled for teaching deductive thinking, and there is justice in that claim. Even the obvious fact that several verifications of a general statement do not prove it, has to be learned and is taught by mathematics. The importance of quantitative knowledge in resolving many problems is one of the greatest methodologies of science.

THE SUBSTANTIVE IMPLICATIONS OF SCIENCE

The values of science extend far beyond the purely factual content of science. Rationalism is one value. There are also those which I shall call substantive implications of science—implications for nonscientific knowledge and values.

Science teaches us that the universe is accessible to man's reason and that its functioning can be described by laws. This very knowledge is of immense value. For example: Fears, dread, and superstitions have been eliminated by just the knowledge that the heavenly bodies follow laws and that these bodies will repeat the past behavior invariably. Man is now the proud possessor of knowledge which enables him to view nature calmly and objectively. We breathe freely because we know that nature is not willful or capricious.

Science gives us factual knowledge about the physical world and man's body. But more important than these are the answers to the questions of why is man born, what is his role in life, and what is his destiny? Since the sixteenth century, science has dealt blow after blow to the egotism of man, who is no longer the central figure in the universe as he was thought to be under the geocentric theory of heavenly motions. Many of the implications of science as to the role and destiny of man are not comforting. Nevertheless, it is helpful to learn the facts. Education demands that we exchange an infantile mentality for a mature one and live with this knowledge. Man's knowledge of himself is very much dependent on his knowledge of the physical world.

The theories of science determine our philosophical outlooks. The role

of science here is enormous. For example, the laws of Newtonian mechanics established the existence of a completely determined universe obeying uniform, invariable, and inexorable laws. Thus arose the philosophy of determinism, which states that the world functions according to a fixed, unalterable plan.

The doctrine of determinism, or at least some aspects of it, have been altered by recent developments in quantum mechanics, particularly the uncertainty principle. It was also challenged by what is called the statistical view of nature, a view itself due to the creation of statistical mechanics in the late nineteenth century. But the point I am making is still valid, namely, that philosophical doctrines are now determined by scientific developments. Should not students know these implications of the theories of science?

Another example of the substantive implications of science is one which affects almost all domains of knowledge, the matter of truth. Science does not claim to offer truths but it does come close, closer and closer some believe, to truth. Science offers theories, not creeds; it offers policies, not dogmas. This is an attitude toward knowledge which is worthy of inculcation.

In the search for truth the sciences offer another value, and here I would emphasize the word search. The scientist is constantly willing to reexamine his theories. He takes literally the word re-search.

An education in science prepares for citizenship in the very civilization which science has fashioned. Our government is heavily involved with science in defense, communications, transportation, health, and numerous other activities. The future citizen may be called upon even as a nonscientist to take a hand in these affairs. The citizen will have to vote on issues which involve science, and the citizen should know also what governments can do to support science. Many leaders are quite ignorant of what basic research is and how it leads to benefits for society. In particular they do not know the long road from pure science to technology.

CONTRIBUTIONS TO ESTHETICS

The third area with which a liberal education is necessarily concerned is the appreciation of the esthetic and emotional values. Science contributes much here, too. Many of these values are accessible only to the professional scientist who undergoes the experiences and acquires the maturity to appreciate them. But one value which I believe can be imparted to young people is the opportunity to create and the pleasures of that act. Probably, young people will not be creating but re-creating with the help of a teacher, but they can begin to feel the emotional satisfactions even from their own little contribution to thought if they are allowed to contribute to building up the knowledge.

For young people I would emphasize the esthetic values that might appeal to the nonprofessional. And there are many of these. Most people are not aware that the greatest period in Western painting, the Renaissance, was fashioned by mathematics. In poetry, science enters into intellectual content. To understand the poetry of an age and appreciate just what the poets were celebrating or deploring, one must know what world-views science had created in that age. The appreciation of poetry on a significant level calls for a knowledge of science.

TEACHING THE CULTURAL VALUES OF SCIENCE

We must teach the cultural values in our science courses. Not to teach the larger cultural significance of science while teaching science is like asking students to swallow food but not letting them digest it.

Another reason for teaching these cultural values in science concerns motivation. Despite the fact that the sciences deal with as real and as significant a world as painting, and poetry, it is much harder to interest students in science and especially mathematics than in literature. First teach the importance and significance of an idea and then examine it in detail. Without the significance, much of mathematics and science appears to be gibberish. Technological applications are a means of arousing interest; use them.

We must teach the broader cultural values in our science courses for still another reason. Knowledge is a whole. Life is not segregated into mathematics, physics, chemistry, and the like, and into distinct values which these subjects offer.

Finally, we must not turn out stunted scientists. Too many mathematicians today are just mathematicians and too many scientists are just scientists. We must develop people who are prepared to live in a world which will make many and varied demands on them and which also offers numerous roads to enjoyments and satisfactions.

SCIENCE AND COMMON SENSE*

Morris H. Shamos

This probing discussion by Morris H. Shamos questions the interpretation of the concept of what is science as it is presented in today's curriculum. Although acknowledging the importance of natural history and technology in the science curriculum, Shamos believes we should resist the tendency to present them under the guise of science. He believes that the purpose of science is to discover the order in nature, not simply to classify it or to put it to use. According to the author, the intellectual values of science must be stressed instead of the technological values.

The past two decades have seen marked changes in the influence of science on our society. When historians look back upon this period it will surely be recorded as an age of science, not necessarily because the public understanding of science is greater now than ever before but because the products of science have influenced so profoundly the affairs of men. It is now reasonably clear that in science, and particularly in technology, what is past is truly prologue. The developments of the past half century, remarkable as they have been, will appear trivial compared with what will occur in the future.

And the trend probably is irreversible. Once shown the practical fruits of science in such dramatic fashion as H-bombs and space flight it is inconceivable that governments, who now look to science as the chief instrument of national growth as well as survival, and the people, who look to it chiefly for the material conveniences it provides and for the prolongation of life, can ever again turn their backs on science. All are irrevocably committed to a scientific society and against such a background the responsibilities of science education take on important and new dimensions.

As a result of the growing national interest in scientific affairs, there has been in the past decade a substantial increase in efforts to improve the scientific literacy of both students and the public. These efforts take many forms, but most noteworthy are the revised courses of study in secondary school science and mathematics that are now under way on a nationwide basis, plus indications that this trend will soon carry down

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into the elementary grades. In the light of these activities, one might "pause to re-think the basic philosophy of science education," as pointed out perceptively in the editorial of the November 1961 issue of *The Science Teacher*. The warning is appropriate for it comes at a time when misjudgment in this area can seriously affect the future development of science in America.

It might be expected that with all this interest in science the task of the science educator would be greatly simplified. Yet this has not been the result. If anything, the problems of science education have been magnified by the sudden "respectability" of science, by the impatience of some educational reformers, and by the realization that those who teach it now share a greater responsibility, and that these teachers are faced with the growing complexity of science itself.

THE COMPLEXITY OF SCIENCE

The complexity of science is, in many ways, the heart of the problem. There is a basic difference, unfortunately, between science and other forms of human knowledge. However much one might deplore the mutual antagonism of C. P. Snow's¹ "two cultures," that they are different can not be denied. The difference lies chiefly in the fact that science and mathematics—and the kind of reasoning that is characteristic of science—are remote from one's everyday experience. By this is not meant the products of science or the outward appearance of nature, for with these one does have a direct kinship. Rather, it means that the basic concepts in terms of which the scientist tries to account for the over-all aspects of nature do not accord with *common sense* understanding.

In fairness one could not say that there ever was a time in the development of science when public understanding of it, or of its purpose, was very good; yet in the present century the difficulty of interpreting science has become pronounced. As Herbert Dingle (University College, London, England) points out, for a civilization so proficient in the practice of science we are astonishingly backward in our understanding of it. The reasons, not difficult to find, are connected with what is usually known as "common sense," or rather with the absence of it.

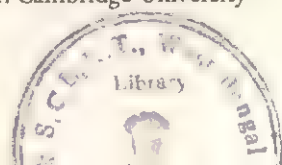
Toward the end of the nineteenth century, when the universe was still described as a well-behaved, deterministic mechanism of moving "billiard balls," it was possible to talk of it in common-sense terms; at least one was not required to stretch his imagination beyond reasonable limits. Now the picture has changed. The basic concepts today, upon which in the final analysis all of science is built, have become so abstract as to defy common-sense understanding. To make matters worse, from the point of

¹ C. P. SNOW. *The Two Cultures and the Scientific Revolution*. Cambridge University Press, New York. 1959.

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view of the general public, determinism has been replaced with probabilism and the universe is now viewed as a cosmic game of chance.

The tenacity with which man tends to cling to common-sense ideas is readily apparent in our everyday activities, as it has been throughout history. What David Hume (1740) called "natural instinct" and Thomas Reid (1764) later termed "common sense" is, in fact, the guiding principle for most of our thoughts and actions. It is well known that in practical life philosophical doubts readily give way to common sense or "natural instinct," and this is what frequently stands in the way of teaching modern science to the average individual. The point was well illustrated by A. S. Eddington some thirty-five years ago in the first of his series of Gifford Lectures at the University of Edinburgh, Scotland.

Eddington spoke of the "two tables" before which he stood and before which science teachers find themselves in the classroom. One is the familiar, commonplace object of the "real" world, the one which can be described in common-sense terms; that is, in terms which evoke meaningful images. It has dimension; it has color; it has substance and some degree of permanence. In short, it is a *real thing*, a common-sense object because by this description one can evoke recognition and understanding among all civilized people. It is unlike space, or time, or temperature, about which reasonable men can form totally inconsistent views.

So much for the "real" table. The other is our scientific table, one which is a total stranger to the real world. It consists mostly of empty space, but with enormous numbers of electric charges (electrons) moving randomly about with great speeds; yet their combined bulk (volume) amounts to much less than one-billionth the bulk of the table itself. Despite this strange construction the table performs "real" functions. It supports things lying on it because the electric charges in it keep colliding (electrically) with similar electric charges in the objects on the table and prevent them from "falling through" the empty spaces. And if one strikes his hand on the table it does not pass through, again because of the electric charges.

But why does this scientific table not fall apart? Again we call upon the electric charges, this time to hold one another in some semblance of order so as to provide the over-all structure of the table. And as Eddington pointed out, the only time the scientific table shows to advantage over the real table is when one sets it on fire and it goes up in smoke. Then what happens to it can be accounted for, while the fate of the real table remains a mystery.

Thus without pursuing this point further, consider how unreal the scientific table must seem to a common-sense individual without going into the complexities of spinning electrons, wave-particle dualism, uncertainty principles, etc. However convincing the scientific table may be to the scientist, it is clear that it will never be easy to persuade the average

person to think *primarily* in terms of this kind of abstraction. The fact is that the science teacher finds it difficult to divorce completely his own thinking from the real table that can be seen and felt.

The entire trend of modern science, whether it be physics or chemistry or molecular biology, is to find a common basis for all of our experience. Scientific inquiry generally begins in the real or common-sense world with observation and in the end it returns to that world in the form of technology or medical advances. The beginning and end are easily understood by the layman but the "in between"—truly the essence of science—is where he tends to become lost.

There are no common-sense counterparts for molecules, electrons, genes, or electric fields. Yet the student demands *concrete* explanations of the things discussed in science. The molecular theory of matter, the kinetic theory of heat, the gene theory of heredity; all relate to concepts not directly accessible to the senses. The lack of a meaningful model is a great disadvantage, of course, particularly when one attempts to teach science to students who are bound by common-sense experiences and who quite naturally tend to reason by analogy with these experiences as a basis.

This is a problem which confronts all science teachers today, and which might be perhaps their greatest challenge; how to guide students through the illusory world of modern science in such a fashion as to leave them with a reasonable understanding of this enterprise called "science." While not entirely impossible it is clearly not a simple task, and grows more difficult the later one begins.

Having seen that modern science is incompatible with what is generally called common-sense understanding, the other side of the coin should now be examined. While on the one hand a scientist may not use common-sense descriptions when talking about scientific theories, he is nevertheless expected to exercise common-sense judgments when talking about educational theories or about the role of science in our general culture. It is in this area that we have not always brought to bear the same degree of logical reasoning demanded in science. This point is perhaps well illustrated by the perennial debate on the question of general education in science.

A COMMON LITERACY IN SCIENCE?

Science teachers are convinced that science and science education are important, and that a common literacy in science should be promoted among all segments of the educated public. Yet as reasonable as this may seem today, and was to many of our predecessors—to Thomas Huxley almost a century ago, to Albert Einstein and George Sarton in more recent times, and even to John Dewey—it is evident that there is no general agreement on this point among nonscientists; and even in the scientific

community considerable differences of opinion on what constitutes a good science curriculum exist.

What then is the basis for believing that science should be part of a liberal education, without specifying for the time being what is meant by "science"? Why should science educators encourage a wider understanding of the nature of science? Should we not be content with educating only those few who are destined to become scientists or engineers, and perhaps to increase this number somewhat in accordance with the needs of our society?

The answer, unfortunately, does not always stand the test of reason. The present era is one in which many of the national and international issues have what may be considered a scientific base; bomb testing, missiles, space exploration, polio vaccines, fluoridation of water, and so on. The intelligent citizen, so this line of reasoning goes, must be prepared to judge these issues and therefore should have some training in science. Think how unrealistic this argument is. What about foreign affairs, social problems, political science, economics, and other similar fields. Must the intelligent person be expert in all these areas in order to be a responsible citizen? The answer obviously is in the negative, however attractive such an educational utopia may seem.

Surely it is clear that the amount of scientific training one can reasonably expect the average person to have would not equip him to exercise intelligent judgment on the scientific merits of issues such as these. Professional scientists, in fact, generally do not have the specialized knowledge in scientific fields other than theirs to evaluate such matters independently—and it is well known, even in one's special field, that while there may be general agreement on questions of scientific interpretation, the interplay between science and society frequently finds scientists at swords' points with one another. The mark of an intelligent person is not necessarily how much he knows, but rather how well he is able to exercise sound judgments with what little he knows. With involved scientific issues, as in all others, this means assessing wisely the opinions of those who are more expert in the field.

An apparent weakness exists, therefore, when one takes as the argument for general education in science, the utilitarian view that it helps to prepare the student in some *direct* fashion for his role in the community. If this were its primary purpose one could certainly make a stronger case against science education than for it.

Another argument one often hears is that as the products of science play an ever-increasing role in our society more youngsters must be directed in science and related fields so as to assure a steady flow of specialists into these areas to fill our future needs. And the way to accomplish this is to expose *all* students to science in the hope that sufficient numbers will be won over.

One must have uneasy feelings about this argument for general

education in science, for it does not appear to stand the test of a democratic society. Moreover, if society needs more scientists and engineers surely this demand could be filled in other, more selective ways than through a "shotgun" technique such as this.

This leaves as the major argument for general education in science the one that generates least enthusiasm among the general public, among legislators, and among many educators; yet it is the one which in the final analysis offers the greatest potential. The development of science is, after all, one of man's major intellectual achievements, a product of the mind which can be enjoyed not for its fruits alone but rather for the sense of order it provides of our environment. The mental stimulation and the satisfaction of learning should be reasons enough for the study of science, just as they are for the study of any other discipline. While this may suggest an ivory-tower approach, it is the only one, in my opinion, which can stand firmly on its merits. When trying to rationalize science education on purely utilitarian grounds, the result is to drive the wedge deeper between this and other forms of human knowledge. The intellectual values of science must be stressed with the practical values as secondary benefits, rather than the reverse, as is now done.

THE SCIENCE CURRICULUM

Assuming that science should be part of the educational experience of all students, of what then should the curriculum consist? This is the same as asking what the average person should know of science. Should he know that the earth is nearly round; that it spins on an axis and rotates about the sun? Should he know that warm air rises, that oxygen is needed to support combustion, how living things function? Of course he should and more! He should know these facts of nature just as he knows various facts of history and geography. They are a part of his natural environment—of his total being.

But this is not science; it is natural history, and here lies the crux of our problem. *How* does one know that the earth is nearly round and spins on an axis? *Why* does warm air rise? *Why* is oxygen needed to support combustion? It is the "how" and "why" of things that constitute science—not the facts alone. The purpose of science is to discover the order in nature, not simply to classify it or to put it to use.

Knowledge of the natural world falls into three broad categories: natural history, science, and technology. Together these constitute the scientific enterprise, but elementary science education consists mainly of the first and last of these categories, with little or no science. The results have not been encouraging as far as public understanding of the nature of the scientific enterprise is concerned, but the reasons why it has generally been taught this way are not difficult to find.

They stem from efforts to relate science *primarily* to everyday experience and thus to stress its practical aspects. Among our earliest impressions are the natural phenomena of our environment, the kind that are seemingly simple and can be presented in purely descriptive fashion. Hence the emphasis on natural history; it is the obvious starting point in a science curriculum, but should not be the end-point as well.

As for the emphasis on technology, this too is easily understood. Our everyday contact with science is through its end products, through the technology that turns on its discoveries. In highly developed countries such as ours, one is literally surrounded by the material products of science. Our habits, our mode of life, our health, perhaps even our freedom to enjoy the arts—all are conditioned by advances in technology. These advances, moreover, result generally from specific needs of society rather than the creative spirit of man. Against such a background it is not surprising that control of nature, i.e., technology, is so frequently confused with man's intellectual desire to understand it, which is the main goal of science.

This has been the general pattern of introductory science education in the past and it is pertinent to ask whether continuing the same practice on a broader scale can ever achieve the goal of a scientifically literate public. The answer must clearly be negative. Even the most casual observer of the educational scene cannot help but conclude that the views of science held by the average adult, and which are derived mainly from just this sort of exposure to science, are at best badly distorted. It is equally evident that somehow our young children, who are fascinated by most experiences with science while in the primary grades, are later repelled by it. Why this aversion to one of man's major intellectual accomplishments?

CONCLUSION

The answer must lie at least partly in the way it is taught. It must be recognized that to achieve our goal requires a major change in the structure of science education. *Science* will have to be taught as well as the usual natural history and technology, and when teaching the latter it is important that they be properly labeled. There can be no reasonable objection to natural history and technology in the science curriculum; on the contrary they are obviously essential. But it is imperative to resist the tendency to present these under the guise of science, especially when it is the only formal introduction the student may have with the world of nature. To give the impression that science consists solely of observation and application is of no great value or service to the students, and certainly not to the cause of science.

TOWARD A THEORY OF SCIENCE EDUCATION CONSISTENT WITH MODERN SCIENCE*

Paul DeH. Hurd

This statement of issues and suggestions by Paul DeH. Hurd provides for the formulation of acceptable purposes in science education and gives some needed insight into the basis for curriculum development. Seven challenging issues of science teaching are presented, together with seven equally challenging viewpoints which offer suggestions for the advancement of science teaching as related to these issues. A logical plan is presented for science teaching that is consistent with the structure of science.

INTRODUCTION

The purpose of this paper is twofold—to describe issues and to make suggestions for the advancement of science teaching. It provides a basis for discussion and debate; it does not pretend to supply answers to all questions that may be raised.

Science curriculum developments are influenced both by changes in society as well as by new developments in science. This means that the curriculum specialist in science needs to examine the writings and research in a wide range of fields: economics, sociology, public policy and manpower, as well as the current status of science. Each of these areas has relevance for the teaching of science.

The development of a literate citizenry in science does not result from the teaching in a single grade nor is it the product of any one course. It can be achieved with a carefully planned kindergarten through grade 12 (K-12) program in which there is a vertical as well as a grade-level coherence within the science curriculum. Curriculum improvement in science then, should be viewed from kindergarten through grade 12 and perhaps through the undergraduate years of college.

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To begin a curriculum reform without first establishing at least a tentative basis for decisions is wasteful of time and effort and seldom produces significant improvements. A major problem in science education in American schools has been the lack of a viable theory of science teaching which could serve as a base for decision making. Consequently the schools can make no answer to their critics. The value of theory in education is that it frees the teacher and the researcher from the constraints of tradition and makes the development of new ideas more likely. It gives perspective to curriculum and instructional issues and provides a basis for making decisions.

Local action groups can make the best use of this document by first comparing it, issue by issue, with their own views on science teaching, noting what they can or cannot accept. Second, they should prepare a clear-cut formulation of acceptable purposes for an education in science, using this as a basis to assess the need and directions in curriculum reform. It should be expected that working groups will wish to change their viewpoints as progress is made in curriculum design and communication between members of the curriculum committee becomes clearer.

In formulating this statement, advantage has been taken of the ideas expressed in the modern science curriculum studies developed over the past decade. At the secondary school level, the works of the Biological Sciences Curriculum Study, the Chemical Bond Approach Project, the Chemical Education Material Study, the Earth Science Curriculum Project, the Junior High School Science Project (Princeton University), and the Physical Sciences Study Committee have been particularly enlightening. At the elementary school level, curriculum studies developed by the American Association for the Advancement of Science, the Educational Services Incorporated, the University of California, the University of Illinois, the Minne Math Science Project, the School Mathematics Study Group, and the United States Office of Education have provided new insights into science teaching.

SCIENCE TEACHING AND CULTURAL CHANGE

A rapidly changing society stimulated by advances in science demands an educational program designed to meet the challenge of change.

Schools exist to help young people know about and participate in the life of their time. In the past when cultural change and progress in science were slow, instruction in science could lag fifty years or more with little ill consequence for the individual or the nation. At the turn of the century, however, America began to move from an agrarian society to a scientific-technological society. Adjustments made in the science curricula reflected new technological developments but generally failed to reflect the advent of modern science. The impact of science on man's thinking, on social conditions, on economic development and on political action

escaped widespread attention, even among highly educated nonscientists. In many ways the influence of science in shaping modern America is the unwritten history of the Twentieth Century.

By the close of World War II it was evident to nearly everyone that America had changed from an agrarian to a scientific-technological society, from rural to metropolitan communities, and that in a thousand related ways our pattern of life and philosophic values had changed. The demand for men and women trained for scientific and technological vocations more than doubled in a decade. But the science curriculum remained static, largely oriented to a culture that no longer existed, and taught from a content that had lost its scientific significance.

Point of View

To escape the threat of obsolescence, education in the sciences must be based upon the kind of information that has survival value and upon strategies of inquiry that facilitate the adaptation of knowledge to new demands.

American schools need a science curriculum suited to recent advances in science and to a changing society. They require courses to prepare young people for change and progress and to help them meet the problems they will face during their lifetimes. A rapidly changing society stimulated by advances in science demands an educational program designed to meet the challenge of change.

Because our culture is characterized by change and progress, the greatest threat to either the individual or national security is obsolescence. This means that an education in the sciences must be based upon the kind of information that has survival value and upon strategies of inquiry that facilitate the adaptation of knowledge to new demands. This education must go beyond the immediate and include the future. What is more important, it should provide young people with the background and intellectual talents for shaping the future in a manner that assures the welfare of human beings and sustains progress. Progress is found not so much in tools and material resources as in the extension of intellectual capabilities of people and the viability of their knowledge. This suggests an education in the sciences that is oriented to lifelong learning, rational and independent thinking, and the acquisition of productive knowledge. A curriculum is needed that is oriented toward a period not yet lived, influenced by discoveries not yet made and beset with social problems not yet predicted. The need is for an education designed to meet change, to appreciate the processes of change, and to influence the direction of change.

The influence of science on national policy, on the thought of our times, on economics, social and political problems, and on the life of each person means that everyone needs an understanding of science. Men and women who do not have this background will be excluded from the

intellectual life of the times and blindly buffeted by the forces that give direction and meaning to modern living. Without a grasp of science they will not be prepared to partake fully of the culture in which they are living.

GOALS OF SCIENCE TEACHING

Science teaching must result in scientifically literate citizens.

Goals of education tend to be an expression of American values. They describe what the ideal American citizen should be like. As such they remain fairly stable over long periods of time. Our conception of the ideal does not change very rapidly. What changes are our ideas of how to achieve the ideals expressed through the goals. Unfortunately the connection between goals and the methods employed to reach them seldom is clear. We encounter very diverse kinds of curricula, all directed toward essentially the same ends. But we possess no satisfactory method for connecting the curriculum to abstract goals.

Point of View

To state the goals of science education is to describe the cognitive skills expected in the student rather than the knowledge assumed essential to attaining these skills.

Goals generally are stated in terms which are much too abstract to be useful as a guide in building a curriculum. It would be more to the point to break general goals down into smaller component steps that could be attained one after the other. Thus, for example, the general goal of producing independent inquirers might be achieved by first discovering what support skills should be learned and which ones should be learned first. Thus, the operative goals for a course would consist of precise statements of specific cognitive skills to be attained each year in science.

Talking about goals is a little like talking about building a bridge. We may know the concept of "bridge" just as we know the concept of "inquiry" but that, by itself, will not suffice to build a satisfactory bridge. We need to know where and for what purpose the bridge will be constructed. Similarly we need to examine the goal of "inquiry" to find out what kind of inquiry and the purposes for which we intend to use the inquiry skills. Once these general questions are answered, criteria or standards for curriculum design, teaching methods, and evaluative procedures may be established.

A statement of goals should describe what we mean by a scientifically literate person living in the last half of the twentieth century. A person literate in science knows something of the role of science in society and appreciates the cultural conditions under which science thrives. He also understands its conceptual inventions and its investigative procedures.

LEARNING SCIENCE

The strategies of learning must be related to the conditions that will lead to an understanding of the conceptual structures of science and of the modes of scientific inquiry.

It is difficult at any time to formulate a satisfactory definition of learning, and it is particularly difficult if we wish to apply this definition specifically to the learning of science. Learning is sometimes defined as the relatively permanent behavior changes which result from experience. The goals of science teaching describe the desired behaviors. We can assume that some teaching procedures and learning materials are better than others for motivating inquiry and for developing an understanding of science concepts.

Point of View

The educational setting and the choice of instructional materials are closely related to achieving the goals of science teaching.

We must assume that the educational setting for attaining the goals of science teaching can be facilitated and that some instructional materials are more efficient than others for achieving goals. In the paragraphs that follow, a few learning principles relevant to science teaching will be identified and their significance for curriculum development and instruction will be illustrated.

One of the first tasks in teaching science is to teach the inquiry processes of science. Inquiry skills provide the learner with tools for independent learning. By means of extensive experience in inquiry the student learns to place objects and events in categories or classes. He discovers the utility of coding systems and becomes aware that systems of classification are not inherent in nature but are man-made. He establishes a conceptual framework. This conceptual framework, in turn, focuses his attention on other phenomena and helps him build new categories which are more comprehensive or more abstract. The conceptual structure ties past experience to the present and serves as a guide for the comprehension and assimilation of new facts and concepts. It serves as a basis for prediction of what will happen in a new problem or situation.

While the significant facts in science change at a bewildering rate, the conceptual structures are more stable. However, we need to recognize that conceptual frameworks also change. The problem is to produce learners with the concepts and modes of inquiry that will permit them to understand these changes.

The ability to form science concepts depends upon the learner's own background and the conditions under which he is taught. To insure in some measure the likelihood that a concept will be acquired, it must be presented and used in different contexts. In a well-organized course of study, concepts formed early in the year are used to develop new concepts

that occur later. Concepts are most easily acquired when familiar and concrete perceptual materials are used. To enlarge the understanding of a concept requires that it be taught many times at different levels of abstraction.

Words facilitate the development of concepts only when the ideas they represent are understood. Verbalization without understanding is likely to hinder the learning of concepts. This is the danger of attempting to teach science concepts through definitions and names. The ability to verbalize a concept is not a guarantee that the learner can apply or relate the concept. Nevertheless, there is an interdependence of concept and language. It is difficult to form a concept without a language rich enough to express it.

How shall we teach the investigatory process that characterizes a researcher and marks the skilled learner? Research provides some suggestions. It is wasteful to teach facts divorced from a meaningful concept. When facts, which have meaning for the learner, are tied into a logically related conceptual pattern, retention is improved and insight is more likely to occur. After learning one pattern, a student tends to respond more systematically to the alternatives in a new situation. An understanding of conceptual structure and training in inquiry help him select what is pertinent in a new situation. The test of learning is the extent to which a student is able to use a conceptual pattern and associated inquiry skills in new contexts.

In any given situation, more than one explanation may seem to apply. There may be no good basis for choosing among alternatives until rather late in the decision-making or problem-solving process. Uncertainties exist during the interval in which the learner actively seeks and processes more data, examines other possible solutions, and finally makes a choice. Children have to be taught to consider alternatives and to recognize that answers must be sought in the environment of the problem, not primarily in the activities of the teacher. That is, they need to learn a pattern of delaying responses and of tolerating uncertainty until sufficient data are collected and alternative hypotheses are evaluated.

These procedures imply that the concepts which form the core of a course must be something more than questions for which students seek answers. Problem-solving is only one small part of scientific inquiry. We are seeking to develop a range of inquiry skills within the structure of a discipline which permits the student to increase his own efficiency in knowing.

The investigative strategies in science and the organization of scientific knowledge suggest valid and desirable principles of teaching. Stressing these procedures has the effect of minimizing authoritarian teaching and encouraging independent learning.

SELECTING THE CONTENT OF THE CURRICULUM

Because science and the cultural scene are in a continuous process of

change, the content of science courses must be constantly re-evaluated and, if necessary, revised to reflect major shifts in thinking and new interpretations of phenomena.

Science is a systematic and connected arrangement of knowledge within a logical structure of theory. Science is also a *process* of forming such a structure. Much of the effort in science is directed toward seeking new knowledge. There is also a certain lack of durability in this knowledge and scientists are dedicated to keeping this so. The significance of facts and concepts is constantly shifting within the scientific discipline. New ideas and theories cause the meaning of present knowledge to change. Correction and refinement are always operating to modify scientific information. And in science there is always more to be discovered and **new relationships to be described.**

Although the information phase of science is tenuous and overwhelming in amount, there are a small number of theories, laws, principles, and inquiry processes which provide the basis for interpreting a great variety of phenomena.

Point of View

To develop a comprehensive science program that will achieve the goals of science teaching, the curriculum-maker must extract the essence of scientific knowledge and define the significant concepts in terms of their usefulness for understanding the structure of science.

Criteria for the selection of curriculum materials should be consistent with the purposes of science teaching and consistent with the structure of science. The task of the curriculum-maker is to extract the essence of scientific knowledge and define the significant concepts in terms of their usefulness for understanding the structure of science. This is a process that begins with the "big picture" of science, not with bits of information, bodies of facts, or concepts in isolation. Thus it is the conceptual schemes and the inquiry processes that provide the framework for curriculum design and for developing courses at each grade level. By this approach we can reasonably expect to develop a comprehensive science program that presents a valid image of a science and will achieve the goals of science teaching.

Criteria for the selection of curriculum materials should be consistent with the purposes of teaching science and consistent with the structure of science.

1. The knowledge must be familiar to the scholar in the discipline and useful in advancing the learner's understanding of science.
2. The content should serve the future as well as the present; therefore the selection of content should focus on the conceptual aspects of knowledge.
3. Every field of science has a basis in experimental and investigative processes. To know science is to know its methods of inquiry.
4. There are connections between the sciences themselves and between the sciences and other

subjects. The content for courses needs to be selected to take full advantage of these relationships and to provide wherever possible a logical integration of knowledge. Transdisciplinary skills, intra- and interdisciplinary understanding should rank high as instructional aims. 5. Only a small fraction of the basic knowledge of science can be selected for teaching in a K-12 program; consequently special attention should be given to including those concepts that are most likely to promote the welfare of mankind as well as the advancement of science. This must also include the knowledge that will enable individuals to participate in the intellectual and cultural life of a scientific age.

ORGANIZING THE SCIENCE CURRICULUM FOR LEARNING

Organization of the science curriculum demands a dominant cognitive pattern.

A science curriculum is a systematic organization of instructional materials designed to achieve the purposes of science teaching with maximum efficiency. The science curriculum developer begins his task by considering the nature of the knowledge he is to work with and what is involved in learning this field of knowledge. Because we are interested in how the pupil gains knowledge and understanding, the implication of cognitive processes for curriculum development must be considered. There are other aspects to curriculum planning, but these are the major considerations.

Point of View

To assure that at every point there will be a readiness for more advanced learning, the curriculum continuum needs to be planned to provide for increasingly complex inquiry skills as well as for growth in the meaning of the conceptual schemes.

The patterning and integrating of information is essential for developing knowledge, suggesting that the logical schematization peculiar to the nature of science should be used in organizing the science curriculum. The materials chosen to form the curriculum should be organized in a manner that requires the learner continually to reorganize, synthesize, and use his knowledge.

A comprehensive curriculum should have unity resulting from a coherent structure and continuity. This suggests that learning should take place in a context which relates to previous knowledge and supplies a foundation for what is to come. The curriculum continuum needs to be planned to provide for increasingly complex inquiry skills as well as for growth in the meaning of significant concepts. This helps to assure that at every point there will be a readiness for more advanced learning. Good curriculum organization establishes its own continuity by making the next steps in learning seem reasonable.

Construction of a science curriculum should not be done in isolation from other parts of the school curriculum. In addition to modes of thought which can be useful in other subjects, there are transcurricular skills such as measuring, coding, observing, and inferring. These skills, rather than information, are the most fertile connections between subjects.

The organizational basis for designing a science curriculum is derived from the nature of science and from the intellectual development of the learner. Conceptual schemes and inquiry processes provide the integrative basis which serves to give both coherence and continuity to the curriculum. Within this framework it is then possible to select information that represents the current status of the discipline and will be most likely to move the learner toward the goals of science teaching.

THE TEACHING OF SCIENCE

A newly conceived curriculum prescribes a style of teaching consistent with the goals of instruction and with the nature of the discipline.

The success of a new curriculum greatly depends upon how it will be taught. A curriculum reform is as much a matter of improving instruction as it is a re-evaluation of course content. A newly conceived curriculum prescribes a style of teaching consistent with the goals of instruction and the nature of the discipline.

Point of View

To encourage independent learning in science, teaching practices should be related to the inquiry aspects of science, to its investigative strategies, and to the structure of scientific knowledge.

A theory of instruction that is particularly suited to the teaching of science is crucial to modern curriculum development. This theory needs to have a broad base and should include the following aspects of instruction: 1. *The nature of science*: its structure, its processes of inquiry and its conceptual schemes. 2. *The nature of the learner*: his motives, cognitive style, emotional background, and intellectual potential. 3. *The nature of the teacher*: his cognitive style, ability to communicate, control pattern, educational philosophy, and understanding of science. 4. *The nature of learning*: its processes, contexts, conditions, and purposes. 5. *The nature of the curriculum*: its organization, its sequence, and its substantive, attitudinal, and procedural dimensions. 6. *The nature of the social structure*: social and cultural forces with their demands and incentives.

Instruction links curriculum with teaching goals. While we have recognized instruction as the role of the teacher, we have not fully recognized it as a function of the student. What the pupil does, determines in some measure what the teacher does, for both pupil and teacher are influenced by the texture of the teaching and learning environment. There

is also an interplay between instructional activities and the materials of instruction and both of these in turn are influenced by the discipline.

LABORATORY WORK IN SCIENCE TEACHING

Laboratory and field work are central to the teaching of science

Learning from work in the laboratory and field is central to the teaching of science. It is here that the student relates concepts, theories, experiments, and observations as a means of exploring ideas. While technical skill and precision are important outcomes of the laboratory, it is the meaning they have for the interpretation of data that is more significant.

Point of View

To achieve its greatest educational value, work in the laboratory must provide opportunities for the student to interpret observations and data.

The laboratory is a place to explore ideas, test theories, and raise questions. Here, meaning is given to observations and data. The data from an experiment remain inert facts until rational thinking makes something more of them. It is at this point that work in the laboratory has its greatest educational value.

Experiments, at whatever grade level, should have a dimension in the investigative aspects of science and provide a variety of experiences with scientific inquiry. Experiments solely for the purpose of gathering data, even though the data are carefully described and summarized, represent merely a preliminary step for understanding science. To collect experimental data is not enough. The student must learn to formulate statements based on data and to test these statements against theory. The conclusion to an experiment is found in the interpretation of data, and it is this interpretation that generates new questions, stimulates further inquiry, helps to solve problems, and leads to the refinement of theories.

A few of the elements of scientific inquiry that need to be systematically introduced throughout science laboratory work are: 1. The variety, characteristics, and limitations of experimental designs. 2. The relationship between experimental options and the nature of the data obtained. 3. The relationships between observed data, experimental results, and the inferences based on the data and results. 4. The tools of measurement and their influence on experimental accuracy. 5. The use of data in generating hypotheses and defining questions and, conversely, the use of hypotheses to guide data collection. 6. The use of theories and models in interpreting data and in making predictions. 7. The analyzing, ordering, and displaying of data in precise and valid ways.

Laboratory work should be seen as a means of relating science concepts, inquiry processes, observation, and experimentation. The child's first

experiences with science, even in the primary school, should involve aspects of experimental inquiry. He should learn how to observe with all of his senses, how to measure, classify, use numbers, communicate, and practice similar subdisciplinary skills. As he progresses through school he should have opportunities to use these knowledge skills to further his understanding of science concepts.

Laboratory experiences need to be planned in both horizontal and vertical sequences, thus providing for progressive learning within as well as across problems. A good laboratory program at any grade level is not a series of "one shot" activities. Some laboratory experiences form substructures for others. The proper sequencing of experiments makes it possible for the pupil to use earlier learning to attack increasingly complex problems.

There are other factors associated with making the best use of laboratory procedures in schools. These include communicating the results of experiments, pacing inquiry skills in science with those in mathematics, and providing for a wider use of mental experiments. We need to recognize that the value of an experiment lies more in the means it presents for exploring the unknown than in the verification of the known.

CONCLUDING REMARKS

It would be rash to suggest that a new curriculum in science has been developed, but it is clear that new viewpoints have emerged. The purpose of this section of "Theory Into Action" has been to present a logical plan for science teaching that is consistent with the structure of science and a modern view of science education.

Not all phases of science teaching have been discussed. There is need for more research and experimentation on some of the proposals. For others, the answers must emerge from one's own rational analysis of the problems. The need for a new approach to science teaching is no longer a matter for debate; it is the nature of the new curriculum that is not clear. The issues and viewpoints presented here are intended to focus discussion and provide a pivot for local action.

HISTORICAL BACKGROUND OF ELEMENTARY SCIENCE*

Herbert A. Smith

The following is a portion of an article by Herbert A. Smith entitled "Educational Research Related to Science Instruction for the Elementary and Junior High School: A Review and Commentary." Dr. Smith traces the history of elementary science education, beginning with its roots in Britain and Germany. He describes the influence of object teaching, the National Education Association Committee of Ten, the nature study movement, and the works of Harris, Hall, Strait, Jackman, Parker, Pierce, James, and Dewey. Two historical landmarks are discussed - namely, the published thesis of Gerald S. Craig in 1927, and the Thirty-First Yearbook of the National Society for the Study of Education in 1932.

The roots of the modern American elementary school science program can be traced through their development of more than 100 years. Two definite influences can be identified as early as the decade of the 1850's. One of these was the didactic literature brought into this country largely from Britain and adapted and then reprinted by American publishers. This instructional literature reflected its origins in an aristocratic conception of education and was designed for use by private tutors or by parents teaching the children at home. It was within the financial reach of only the upper classes. Most of this material was directed to children's observation and to study of natural phenomena. Underhill has traced the didactic literature to the influence of such men as Francis Bacon, John Locke, and other writers who at that time were stimulating democratic thought in Europe as well as in America.¹ When the National Education Association was organized in 1857, it helped to stimulate the task of adapting some of this literature for use in school classrooms.

The second influential factor during the late 1850's rose from the "Pestalozzian object teaching" movement. This method of teaching was very widespread and was an international educational development. The applications made of the method varied greatly from one country to another. In Germany it developed into *Heimatkunde*,² or "community study." In England and in the United States object teaching evolved into,

* REPRINTED FROM *Journal of Research in Science Teaching*, Vol. 1, Issue 3, 1963, pp. 200-205, 223, by permission of the author and the editor. Dr. Smith is Professor of Education at Colorado State University, Fort Collins.

and was later supplanted by, nature study. However, the American and English versions of nature study varied greatly in spite of their common origin in object teaching.

The best known American adaptation of the Pestalozzian method was developed at Oswego, New York. Due to the influence of the National Education Association which supported it, the "Oswego method"³ was given nearly universal acceptance in this country. The new method aroused interest in the revision of content and in the method of study in the rapidly growing elementary schools.

The methodology of object teaching had a highly formal structure which tended to obscure the legitimate purposes of science instruction; it did not contribute effectively to a sense of sequence and direction. Men like Franklin and Jefferson had encouraged the development of science in elementary education hoping for and working for programs that had merit due to their continuity and practicality. Object teaching destroyed whatever gains had been made in this direction because the emphasis tended to shift to mere description of animate and inanimate objects and to neglect the interpretation and understanding of events and phenomena. The content was further fragmented by the organization of information concerning the particular object of study into formal separate sciences, thus imposing a mature scientist's view on children. Profound meanings tended to be neglected in favor of mere obvious descriptions.

The old method of object teaching tended to be supported by the principles of faculty psychology.⁴ The emphasis on observation and memorization for very young children was based on the assumption of the sequential development of capacities. It was falsely assumed that young children were able only to observe and identify objects but were unable to reason or to interpret phenomena. In addition, the specialized methodology of object teaching, together with the exclusion of the use of books, made heavy demands upon the ability and knowledge of the teacher. It appeared to be particularly ill-suited to the purposes and needs of teachers and pupils in a rapidly developing industrial society.

Some insight into the nature of the ideas underlying the "object study" movement may be gained from the following selected excerpts. The method was:

to place objects before them [children] in which they are interested, and which tend to cultivate their perceptive faculties; and, at the same time, lead them to name the object, to describe its parts, and to state the relation of these parts. Thus, language also is cultivated; and, from the observation of a single object, the pupil is led to compare it with others, and the first steps in classification are taken.

... These lessons are designed specially to cultivate the perceptive faculty; and hence, in any true system of education, they must be considered as fundamental—not only in their relation to the faculties, but as giving the first ideas, or laying the foundation of all branches of knowledge. Object Lessons in form lead directly to

Drawing, Writing, and Geometry; in sound and form, to Language, including Reading, Speaking, and Spelling; in place, to Geography; and in animals, plants, minerals, etc., to Natural History. . .

This method commences with an examination of objects and facts, then institutes comparisons by which resemblances, differences, and relations are observed, and with the results so obtained, repeats the process until the remotest relations are known and the highest generalizations reached. This process may, with propriety, be called the **Objective Method or Objective Teaching**.

Objective Teaching, in this enlarged sense, includes object lessons, and a great deal more. It comprehends the unfolding of the faculties in the order of their growth and use, and the presentation of the several branches of instruction in their natural order. Its great aims are mental growth and the acquisition of knowledge.⁵

The decade of 1870 witnessed the culmination of a number of developing trends. The writings of such men as Herbert Spencer⁶ in his essay, "What Knowledge Is of Most Worth," and the rising importance of science and technology had forced the consideration of science as a field of study upon the public. It was during this decade that colleges and universities first came to accept science subjects as satisfactory prerequisites for admission to colleges.

The depression of 1873 spurred a critical examination of the program of the public schools; and the elementary schools, particularly, were the object of a veritable storm of abusive criticism. Tax-conscious citizens were demanding clarification of the aims and purposes of education. Most of the educational journals joined the hue and cry for more science in the public school programs. There were accompanying changes in the social and economic patterns of the time. Old patterns of teaching and learning were seen to be ill-adapted to the changing times and not fully in accord with characteristics of the learning process.

Near the end of the 19th century, the National Education Association sponsored an extensive study at the secondary school level that was to influence the entire educational system. This was the work of the National Education Association Committee of Ten. The results of this Committee's study tended to stabilize science offerings and led to the discontinuance of a large number of short-term specialized science courses taught in the secondary school. The report put emphasis on laboratory and other direct experiences and on the need for special training for science teachers. Its influence was effective primarily on textbooks, syllabi and other instructional material. These changes at the secondary level were reflected rather quickly in the elementary schools. It was only after the report of the Committee of Ten that materials for pupil use and teacher planning appeared in any appreciable volume.

A number of men rose to prominence in the field of elementary school science around the turn of the century. Of these, William F. Harris⁴ first translated philosophy and educational theory into a specific and extensively detailed elementary science curriculum which provided help to

teachers in the field. G. Stanley Hall⁷ and Colonel Francis W. Parker⁸ contributed general philosophies of education supporting nature study. These philosophies opened the way for others to experiment and to work out detailed elementary programs, especially in elementary science. Much of this work was done by Henry H. Strait and Wilbur S. Jackman at the Practice School of the Cook County Normal School, later the Chicago Institute, and now the School of Education at the University of Chicago.¹ Parker strongly supported the work of Strait and Jackman in Chicago, influencing the use of science as a unifying principle in elementary school curricula. Jackman's writings represent a connecting link between early writers of children's literature and modern elementary science. His positive, dynamic view of children and science is in close accord with modern ideas. Jackman's contributions to elementary science were obscured for a time by the extended development of a nature study movement.

Liberty Hyde Bailey and associates at Cornell University were prime movers of the nature study movement. They were motivated by the need to improve agriculture and to halt the increasing migration of young people from farms to cities where they would add to already swollen city relief rolls.⁹ One of the important publications to come out of Cornell was the *Handbook of Nature Study* by Mrs. Anna Botsford Comstock which ran through many editions after 1911. This book, along with the Cornell rural school leaflets was, and still is, widely distributed to schools. These and other publications by the Cornell group rank among the most comprehensive efforts in teacher education ever undertaken in the field of science education. Like object study, nature study was based on the principles of faculty psychology and on the alleged serial development of traits. The child was considered in terms of his limitations rather than in terms of his capabilities. Nature study had been developed by specialists in science who lacked the perception and understanding of men like Jackman who were specialists in science as well as experienced teachers of children.

By the 1920's the enthusiasm for nature study was beginning to wane. The influence of the new designs in curricula for science was beginning to be felt. In addition, new thinking in other fields was again beginning to make an impact on all of education and was particularly relevant to science instruction. Men of the stature of Charles Sanders Peirce,¹⁰ William James,¹¹ and John Dewey¹² were having tremendous influence on education. William James and Charles Sanders Peirce had contributed a theory of pragmatism which meant in essence that the meaning of a conception is to be found in the working out of its implications. The link between concept and experience was seen as fundamental. Peirce's thinking was basic to the development of the operational theory of meaning which was closely associated with the development of pragmatism. Dewey's contributions were numerous; but, perhaps, the

most significant for the developing field of elementary science was his contention that the methodology of science is at least of equal—or perhaps of greater—significance than the actual knowledge accumulated. The present emphasis on “science as inquiry” would seem to be a reaffirmation of a position which Dewey took nearly half a century ago. It was apparent by the middle of the 1920’s that nature study was no longer a satisfactory vehicle for a modern science program. Its whole rationale was no longer consistent with the psychology, philosophy and methodology of the time. It was inconsistent with the existing social and economic realities. With the benefit of historical perspective it is patently obvious that a substantial change in the science program for the elementary school was in order.

It is probably no exaggeration to say that Columbia University was, at that time, the colossus of American education as a training institution for public school administration and for other general leadership positions in the educational field. In 1927 a thesis was written at Columbia which came at a time when the situation was ripe for change. It represented the then most prestigious institution in professional education and was to have, perhaps, the most far-reaching influence on the development of elementary science of any single event in the history of the field. The study was entitled *Certain Techniques Used in Developing a Course of Study in Science for the Horace Mann Elementary School*.¹³ It represented the culmination of three years of work by Gerald S. Craig at the famous laboratory school and profoundly affected subsequent developments in elementary school science. Craig turned his back resolutely on the nature study movement and, in so doing, took note of the great chaos of educational goals to which lip service was then being paid. These goals included various esthetic, ethical, spiritual, intellectual, and civil-training goals without adequate indication as to how such aims were to be achieved. Parenthetically, it is perhaps worth noting at this point that the question of purposes is one which is still not fully resolved, although it is certain that there is far more unanimity as to the purposes and ends to be served today than there was at the time that Craig was doing his original study. Some of the present arguments and debates in the profession represent confusion among the disputing parties as to the real purposes to be served by the elementary science program. Craig saw the function of science in the elementary school to be significant in terms of general education, pointing out that the laws, generalizations, and principles of science have vital meanings to individuals regarding numerous questions which confront them. He also saw the utilitarian aspect as it is related to health, safety, and the economy. He was aware, moreover, of more than the cognitive aspects of science instruction and emphasized also the affective dimensions: attitudes, appreciations, and interests. Clearly, Craig’s thesis has been one of the landmarks in elementary science and is basic to much of the later writings in the field including his own.

Another important step forward was taken when the Thirty-first Yearbook¹⁴ of the National Society for the Study of Education was published in 1932. This Yearbook presented a plan for an integrated program of science teaching. This marked the beginning of a trend which has continued to be more and more emphasized down to the present time. Problems involving sequence and articulation of science instruction between the various grades and school units have continued as vexing difficulties. The National Science Teachers Association has had a committee at work for several years on the K-12 science program. Others are equally concerned with problems of articulation between high schools and colleges. The design of an appropriate sequential series of science experiences which shall extend from elementary school through college is a problem which has occupied the thinking of many persons. This problem has stimulated study of such diverse questions as content and placement, when track programs should be instituted, when non-science and non-college bound students should terminate their study of science, when advanced placement programs should be used, and how elementary teachers should be educated. These questions are obviously inter-twined with conceptions of the ultimate purposes and goals of education and no universal agreement has been attained as to what these should be. Perhaps no such agreement is possible or even desirable; but an understanding of the problems and their complexities would at least reduce the confusion.

The Thirty-first Yearbook also placed an emphasis on the major generalizations of science as objectives of instruction. This emphasis had profound effects on course syllabi and textbooks, and a generation of these documents tended to emphasize the understandings and applications of the principles of science. One other obvious example of the Yearbook's influence was the great amount of research devoted to identifying the major principles of science which were of significance to general education. In fact, a great body of the research that was subsequently done in science education was a reflection of the influence of this famous Yearbook. The Yearbook was clear and definite in its support of elementary science rather than nature study and, as a result, it contributed to the rapid advancement of science at the elementary school level. The report advocated basing the selection of science content on personal and social criteria; thus, probably, both conforming to and augmenting the educational thinking that was then developing in this direction.

The Society also devoted its Forty-sixth Yearbook, published in 1947, to problems of science education. The increasing impact which science was obviously having upon the social, cultural, and economic affairs of men continued to be very much in evidence in the thinking revealed in this Yearbook. The following quotation is illustrative of this fact.

Instruction in science must take cognizance of the social impact of developments produced by science. It is not enough that they be understood in a technical or

scientific sense; it is most important that their effects on attitudes and relationships of people be studied and understood. Science instruction has not only a great potential contribution to make but also a responsibility to help develop in our youth the qualities of mind and the attitudes that will be of greatest usefulness to them in meeting the pressing social and economic problems that face the world.¹⁵

There is a marked sensitivity to some of the "affective" objectives of science instruction in this Yearbook. There is also a more obvious reflection of sensitivity to the responsibility which educators have to prescribe the precise way in which statements of intangible and illusive objectives can be translated into practical programs and to determine how the effectiveness of instruction can be measured.

The most recent document prepared by the National Society for the Study of Education of primary concern to science education was the Fifty-ninth Yearbook which was published in 1960. This Yearbook takes cognizance of the increasing dependence of society on science. The implications for the scientific training of citizens of such a society are clearly considered to be of fundamental importance. The Yearbook goes further than preceding reports of the society in stressing that characteristic of science which is known as "process" or "inquiry." It is perhaps significant to quote the Yearbook with respect to this latter observation.

One function of the elementary school has always been to help children learn a part of what they need to know from the world's storehouse of knowledge. In recent years this function has embraced more and more science. Scientific methods of investigation, by which knowledge may be acquired and tested, are now very much a part of our culture. The elementary school should help children become acquainted with these methods.¹⁶

One may summarize the historical overview by pointing out that the past century has been a century of unprecedented social, economic, scientific, and technological change. The elementary schools are to a very large degree a mirror of the ambient culture, and they are probably more sensitive to social change than any other educational level. They are always, to a degree, consonant with the prevailing philosophies and state of knowledge in existence at any particular time. Fundamental changes in philosophy, in theories of child rearing and educability, in the need for universal and extended educational training for all children and adolescents of our society with capacity to learn, have been accepted within this century. Science, itself, has progressed from the dilettantism of the leisured intellectual to a basic and fundamental activity of a substantial percentage of mankind. No human being of any civilized nation can remain untouched by these multifarious developments. In such a milieu it is not surprising that elementary science instruction has been beset by numerous perplexing problems.

References

1. Underhill, Orra E., *The Origin and Development of Elementary School Science*, Scott, Foresman and Company, Chicago, 1941.
2. Shoemaker, Lois Meier, *Natural Science Education in the German Elementary Schools*, Bureau of Publications, Teachers College, Columbia University, Contributions to Education, No. 445, New York, 1930.
3. Lammers, Theresa J., "The Thirty-first Yearbook and 20 Years of Elementary Science," *Science Education* 39, 39-40 (February, 1955).
4. Craig, Gerald S., "Elementary School Science in the Past Century," *Science Teacher*, 24, 4, 11-14 (February, 1957).
5. Krusi, Hermann, *Pestalozzi His Life, Work and Influence*, Wilson, Hinkle and Co., Cincinnati, 1875, pp. 162-164.
6. Spencer, Herbert, "What Knowledge Is of Most Worth?" in *Education*, Appleton, New York, 1926 (Reprinted from 1860 edition).
7. Hall, G. Stanley, *Aspects of Child Life and Education*, Appleton, New York, 1921.
8. Parker, Francis W., *Talks on Pedagogies*, Kellogg, New York, 1894.
9. Comstock, Anna Botsford, *The Comstocks of Cornell John Henry and Anna Botsford Comstock, An Autobiography by Anna Botsford Comstock*, Comstock Publishing Associates, New York, 1953.
10. Peirce, Charles Sanders, *Philosophical Writings of Peirce*, Dover, New York, 1955.
11. James, William, *The Principles of Psychology*, Holt, New York, 1890.
12. Dewey, John, *Democracy and Education*, Macmillan, New York, 1916.
13. Craig, Gerald S., *Certain Techniques Used in Developing a Course of Study in Science for the Horace Mann Elementary School*, Bureau of Publications, Teachers College, Columbia University, Contributions to Education, No. 276, New York, 1927.
14. National Society for the Study of Education, *A Program for Teaching Science*, Thirty-first Yearbook, Part I, Public School Publishing Company, Bloomington, Illinois, 1932.
15. National Society for the Study of Education, *Science Education in American Schools*, Forty-sixth Yearbook, Part I, The University of Chicago Press, Chicago, Illinois, 1947, pp. 1, 145-147.
16. National Society for the Study of Education, *Rethinking Science Education*, Fifty-ninth Yearbook, Part I, The University of Chicago Press, Chicago, Illinois, 1960, pp. 112-113.

SCIENCE IN THE ELEMENTARY SCHOOL*

Paul E. Blackwood

Paul E. Blackwood reports on a study of the status of elementary science education in the United States today. This survey of practices encompasses objectives, extent of science teaching, teaching patterns, departmentalization, consultant services, curriculum sources, time allocations for science teaching, equipment, expenditures for elementary science, science clubs, and some barriers to effective science teaching. The study reveals many inadequacies in the science program of elementary schools. Dr. Blackwood makes five recommendations for the improvement of elementary science teaching based upon the findings of his study.

Nearly all public elementary schools in the United States teach science at some time during the school year. This statement, though true, covers wide variations. Schools treat science as a separate subject or as incidental to another subject. They give several hours a week to science teaching or only minutes. A few schools have special teachers, but most rely on the classroom teacher, with or without the help of a specialist, to teach science. Budget allowances for science equipment and material are ample and scant—and every degree between.

These facts and others have come to light in a recent study completed by the Office of Education on science teaching in the elementary schools of the United States in school year 1961-62. A full report on the study will be issued in an Office publication (*Science Teaching in the Elementary School: A Survey of Practices, 1961-62*) now in press. This article is a report on some of the highlights of the findings of the study.

Information for the study was obtained from a questionnaire sent to a representative sample of the Nation's more than 87,000 public elementary schools. Schools in every State were included, but the study does not report the status of science teaching by region or by State. Questionnaires were sent to individual, general purpose elementary schools rather than to school systems, and they were completed by principals with the help of teachers.

Replies to the questionnaire have been broken down by enrollment for schools and administrative units (districts). The breakdowns by schools are 800 and over, 400 to 799, 50 to 399, and 49 and under; by districts,

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25,000 or over, 6,000 to 24,999, 3,000 to 5,999, 600 to 2,999, and 599 and under.

OBJECTIVES

The questionnaire began by asking schools to rate as *very important*, of *some importance*, and of *little or no importance* 10 commonly accepted objectives of science teaching. The respondents rated nearly all of the objectives as *very important* or of *some importance*. Only one—to develop scientists—was not considered *very important* by at least 40 per cent of schools. See Table 1.

TABLE 1

The Importance of 10 Objectives of Science Teaching as Rated by Public Elementary Schools (Ranked by Per Cent of Response to Very Important)

<i>Objective</i>	<i>Very Important</i>	<i>Of Some Importance</i>	<i>Little or No Importance</i>
1. To help pupils develop curiosity	87.0	12.0	1.0
2. To help pupils learn to think critically	85.2	14.3	0.5
3. To introduce pupils to typical science topics—weather, electricity, plant and animal life	84.3	14.9	.8
4. To help pupils acquire knowledge of their environment	84.2	15.5	.4
5. To help pupils develop an appreciation of their environment	82.4	17.1	.5
6. To develop problem-solving skills	73.9	24.2	1.9
7. To develop in pupils a sense of responsibility for the proper use of science	69.3	27.7	3.0
8. To prepare pupils for high school science	42.8	45.2	12.1
9. To develop hobbies and leisure-time activities	40.9	50.4	8.7
10. To develop scientists	17.6	51.8	30.6

EXTENT OF SCIENCE TEACHING

Only a very small per cent of all schools did not teach science at all. Three-fourths or more taught science at every grade level except kindergarten for at least one-half the year; 4.5 per cent did not teach science in kindergarten, and 4.4 per cent did not teach it in the first grade.

The per cent of schools teaching science more than half a year varied by grade and size. More large schools than small taught science more than half a year in almost every grade. In the third grade, for instance, the per cent ranged from 70 in the 49 and under schools to 90 in schools enrolling 800 and over. Figure 1 gives the per cent of public elementary schools teaching science more than half a year by grade.

TEACHING PATTERNS

Schools were asked to indicate which of these five titles most aptly described the science teaching pattern they followed:

Per Cent

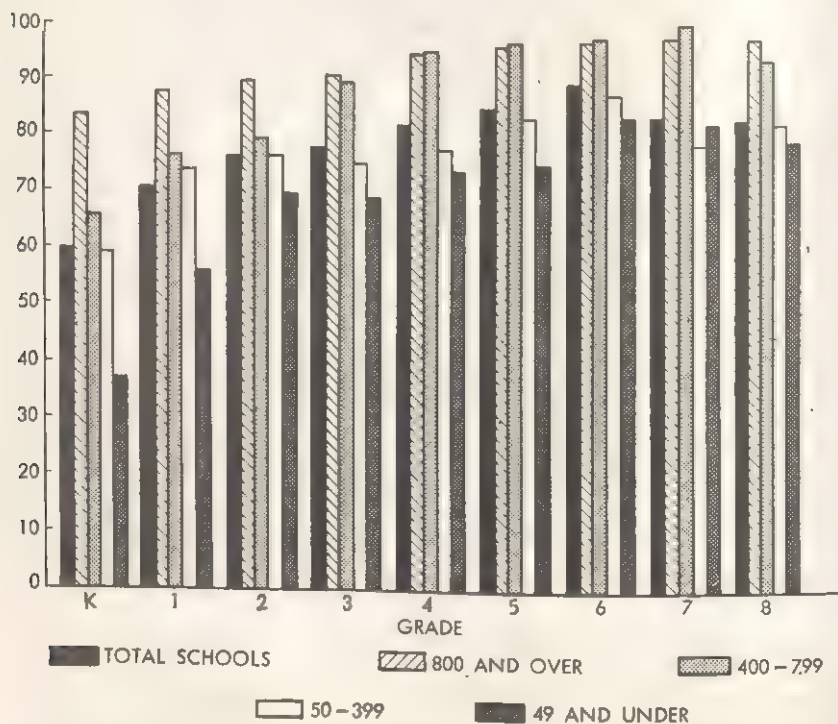


FIGURE 1.

Per cent of public elementary schools that teach science more than half a year, by grade.

(1) *Taught as a separate subject*, (2) *integrated with other subjects*, (3) *incidental*, (4) *separate subject and incidental*, and (5) *integrated and incidental*. The replies indicate that the grade level made a difference. In the upper grades schools most often followed the pattern *separate subject and incidental*; in the lower grades, *integrated with other subjects*. In other words, the percent of schools teaching science as a separate subject increased by grade. In the 400 to 700 group of schools, for example, the range was from 13 per cent in kindergarten to 89 per cent in the eighth grade. See figure 2.

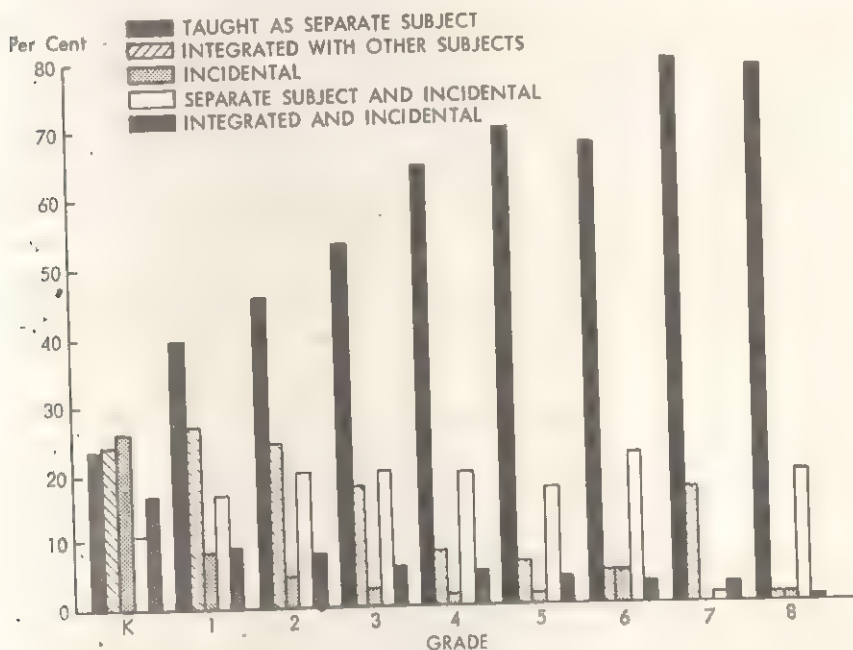


FIGURE 2.

Per cent of public elementary schools that teach science by various patterns, by grade.

DEPARTMENTALIZATION

Most schools were not departmentalized, that is, they did not provide special science teachers. Only about 15 per cent were departmentalized at some grade level. This percent varied by school size as follows:

Enrollment	Per Cent of Departmentalization
800 and over	36.5
400-799	21.8
50-399	18.5
49 and under	.08

THE TEACHERS

The study found that the classroom teacher was the person most frequently teaching science in all grades in all schools. But the per cent of schools in which science was taught only by a classroom teacher decreased progressively from the first grade (86.5 per cent) to the seventh (72.9).¹ About 8 per cent of the schools provided special assistance to the classroom teacher through a specialist in the central office. Although a large per cent of the smaller schools did not have special science teachers, schools in every enrollment group had specialists available, particularly the *800 and over* group. About 30 per cent of the schools in this group reported that a special science teacher from a central office was available to help classroom teachers in kindergarten through grade six.

A small per cent of the schools reported that television was the primary source of science teaching. Though the per cent was small, it may be significant in view of the widespread interest in educational television. The practice was most common in the large schools; none in the *49 and under* group reported using television.

See Table 2 for the findings on the source of science teaching in the elementary school.

CONSULTANT SERVICES

About 42 per cent of the schools had some type of consultant help in science available to teachers. Of these, nearly 40 per cent depended on general elementary supervisors. About 15 per cent had elementary science consultants, although the per cent ranged from 39.5 per cent in the *800 and over* schools to 5.6 per cent in the *49 and under*. High school science teachers were available for consultation in 27 per cent of all schools having help, particularly in schools in small administrative units.

The questionnaire asked schools which had consultant service to indicate by grade level whether teachers used this help *very often* (at least once a week), *occasionally* (once a month), or *rarely or never* (less than once a month), and to indicate on a list of nine the ways they used consultants. Roughly 50 per cent of the schools used consultants *very often* or *occasionally* in kindergarten through grade 3 and about 60 per cent used them *very often* or *occasionally* in the upper grades. The responses to the list of ways consultants are used show considerable variation from one enrollment group to another, but all groups indicated that consultants were used most often to provide materials and to plan and consult with teachers. See figure 3.

¹ The grades 7 and 8 represented in this report are in schools organized by grade levels, kindergarten through 8. It does not report on conditions in grades 7 and 8 in junior high schools, where the per cent of special science teachers is higher.

TABLE 2

Source of Science Teaching in Public Elementary Schools: Percentage by Grade

Source	Grades—All Schools								
	K	1	2	3	4	5	6	7	8
Classroom teacher only	84.0	86.5	86.6	84.4	82.6	80.4	77.0	72.9	72.9
Classroom teacher with help from science specialists attached to school staff	5.5	5.0	4.8	6.2	6.8	6.2	6.4	4.4	4.6
Classroom teacher with help of science specialist from the central office staff	10.1	7.5	7.5	7.6	7.6	7.6	7.6	1.5	2.5
Special science teacher on the school staff	.0	.1	.3	.3	.9	2.2	3.4	15.7	15.8
Special science teacher on central office staff	.0	.0	.0	.1	.1	.1	.1	.1	.0
Classroom teacher with special competence in science in lieu of regular classroom teacher	.0	.6	.6	.8	1.0	1.6	3.3	4.6	4.0
Television	.4	.3	.3	.7	1.1	1.8	2.1	1.0	.1

CURRICULUM SOURCES

The questionnaire asked schools to indicate the frequency of use (*very often*, *occasionally*, or *rarely or never*) by grade of (1) State guides for courses of study, (2) administrative unit guides, (3) local school guides, (4) textbooks, and (5) teacher's own ideas. Over one-third of the schools said they used guides provided by the State *very often* in grades 7 and 8 and over one-fourth in grades 1, 2, and 3. Over 50 per cent of the 800 and under said they used State guides *rarely or never*. But about 50 per cent of the 49 and under schools used State guides *very often*. All in all, schools in the small administrative units tended to use State guides more often than schools in other units.

LOCAL SCHOOL GUIDES. A higher per cent of the larger schools used local guides *very often* than did the smaller schools, at every grade level. But a relatively high per cent of schools *rarely or never* used local school guides, probably because they were not available.

TEXTBOOKS. A high per cent of the schools, 78.1 to 90, reported that they used textbooks *very often*, except in kindergarten (where textbooks

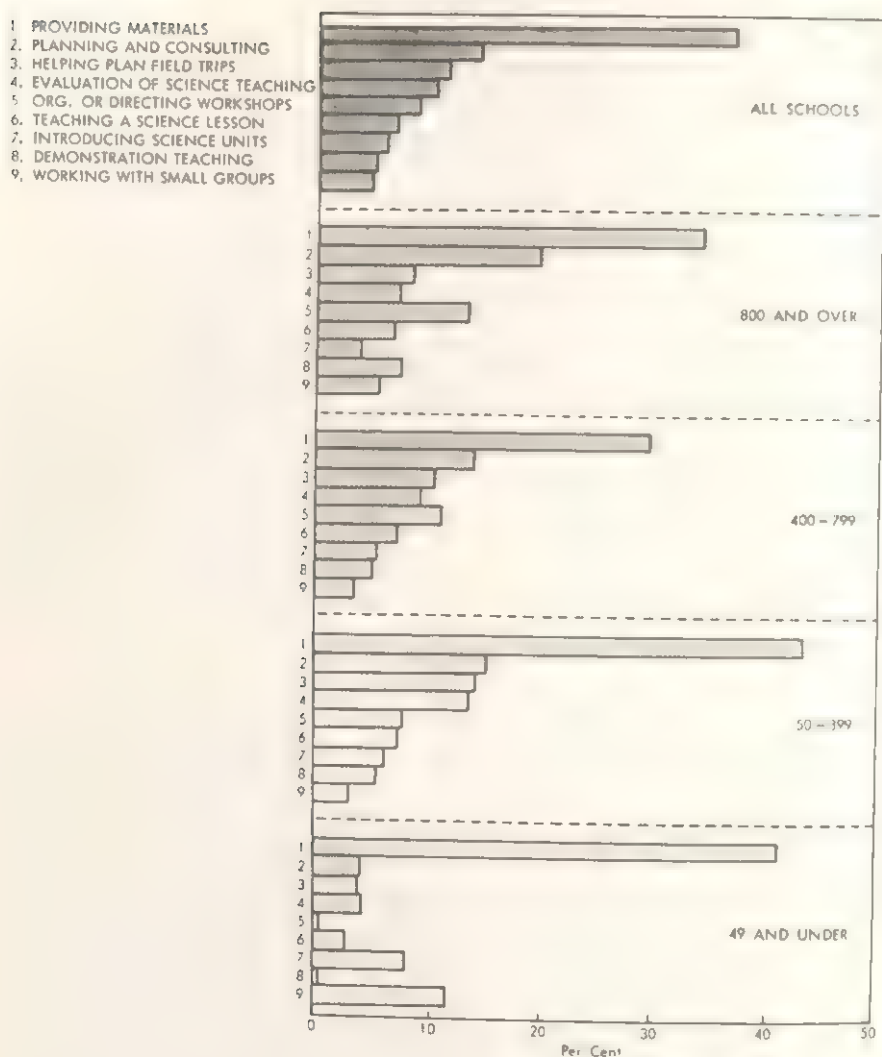


FIGURE 3.

Nine ways consultants are used in teaching science, ranked within school enrollment groups.

are rarely used at any time). The per cent of schools using textbooks *very often* increased from the lower grades to the upper grades in every administrative unit enrollment group.

ADMINISTRATIVE UNIT MATERIAL. The per cent of schools using science guides developed by the administrative unit rose with the size of

the unit enrollment. More than 50 per cent of the schools in the largest administrative unit group, at every grade level, used an administrative unit science guide *very often* in contrast to 10 per cent in the *500 and under* administrative unit. About one-fourth of the schools used the guides *rarely or never* in the large school systems, compared to three-fourths of the smaller school systems. The largest schools also tended to use administrative unit guides far more than small schools. It is important to realize, however, that schools may have marked *rarely or never* because no guides were available.

TIME GIVEN TO TEACHING

Schools usually taught science two, three, or five periods a week. But what do these periods mean in terms of minutes, a better measure of the time given to science teaching? A small but significant per cent of all schools taught science less than 20 minutes a week at almost every grade level, particularly the *49 and under* schools. In the lower grades only a small per cent of schools taught science as much as 200 minutes a week (an average of 40 minutes a day), but in the fifth through eighth grades a substantial per cent of schools taught it more than 200 minutes a week.

EQUIPMENT

The questionnaire listed 42 selected items used in science teaching, ranging from the simple and common, to the expensive and unusual, and asked schools to report how many of each item were available for use in the school. The list was not all inclusive, nor was it presented as a model list since the equipment requirements of a school depend on its curriculum. It did, however, contain items which curriculum guides and elementary science books frequently mention.

For almost every item the mode number (that is, the number most frequently reported) was *zero*. In no instance was it greater than *one*. The schools in the *800 and over* group fared best. But even in this group, though many schools had enough equipment for a demonstration type program, they did not have enough for a program of individual investigation. The *50 to 399* and the *49 and under* schools reported an extreme dearth of items by actual count.

As to the availability of equipment, the difference among enrollment groups was most striking. The smaller the school, the less available and the less adequate the equipment and supplies. Over one-fourth (26 per cent) of the *49 and under* schools compared to less than 1 per cent of the *800 and over* schools, for example, reported that equipment and supplies were completely lacking. Eight per cent of all schools said that equipment and supplies were *very plentiful*; 46 per cent, *generally adequate*; and 46 per cent, in the two categories, *far from adequate and completely lacking*.

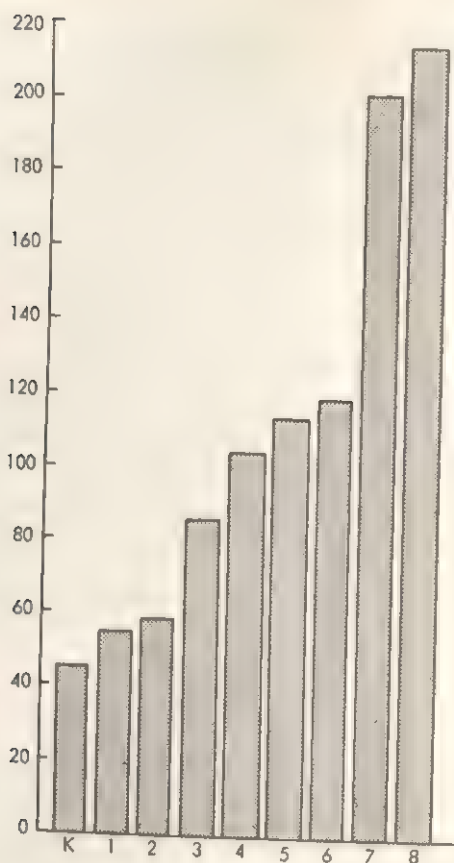


FIGURE 4.

The number of minutes a week given to science teaching in schools in the 400 to 700 group.

EXPENDITURE FOR SCIENCE

The mean expenditure by school enrollment was from 44 cents to 60 cents a pupil. The mode number, however, indicates that the largest per cent of schools spent from 11 to 14 cents per pupil. The 49 and under schools spent as much per pupil as the larger schools, but the amount spent by these schools was inadequate to support good programs. The percentages of all schools in each of several expenditure categories were these:

<i>Amount Spent Per Pupil</i>	<i>Per Cent of Schools</i>
0-20 cents	40.1
21-40 cents	9.4

<i>Amount Spent Per Pupil</i>	<i>Per Cent of Schools</i>
41-60 cents	11.7
61-80 cents	10.6
81 cents-\$1	4.6
\$1.01-\$1.24	4.6
\$1.25-\$1.50	3.4
\$1.51 and over	15.6

These figures do not show, however, that nearly 50 per cent of the *49 and under* schools spent from 0 to 20 cents annually per pupil and that 21 per cent spent over \$1.51 annually per pupil. On the other hand, only 4.3 per cent of the *800 and over* schools spent as little as 0 to 20 cents per pupil, and 9.2 per cent spent \$1.51 and over.

SCIENCE CLUBS

On the question of whether they thought science clubs desirable, 75 per cent of all schools said yes. But to the question on whether they had science clubs, only 7 per cent said yes. Generally, the larger the administrative unit, the higher the per cent of schools with clubs: 20 per cent of the *800 and over* schools had clubs, but only 5 per cent of the *49 and under*.

BARRIERS TO EFFECTIVE TEACHING

Of 13 items listed by the questionnaire as "barriers to effective science teaching," the schools indicated that "lack of consultive service" is the greatest barrier. There were differences of opinion, however, among the groups. "Inadequate room facilities" ranked first with the *800 and over* schools and the *400 to 799* schools, though it was third with the other two groups. The *49 and under* schools checked "lack of supplies," "lack of consultant help," "not enough money," and "not enough time for instruction" as the greatest barriers. See table 3.

RECOMMENDATIONS

The data obtained by this study seems to point to inadequacies in the science programs of some elementary schools. Many changes will be necessary before these schools can eliminate them. The findings of the study point to these recommendations:

1. Schools should determine whether the time they give to science teaching is enough to provide sound and adequate instruction.

2. Schools teaching science incidentally should reassess the advantages and disadvantages of this method in comparison with programs based on systematically planned curriculums.

3. Schools with inadequate supplies should acquire more materials and equipment. Small schools and small administrative units, particularly, need to put more effort into obtaining and using science equipment and supplies.

4. Schools need to develop and take part in inservice programs for teachers to help them update knowledge and acquire better methods.

5. Schools need to identify additional consultant resources, particularly for the classroom teacher who most often teaches science in elementary schools.

TABLE 3

Barriers to Effective Science Teaching in Public Elementary Schools Ranked by Replies from All Schools and by Enrollment Groups

Barrier	Ranking by School Enrollment Groups				
	All Schools	800 And Over	400 To 799	50 To 399	49 And Under
Lack of consultant services	1	4	3	1	2
Lack of supplies	2	7	5	2	1
Inadequate room facilities	3	1	1	13	8
Insufficient funds	4	6	6	3	3
Teachers lack sufficient knowledge of science	5	2	2	4	7
Insufficient inservice opportunities	6	10	8	7	5
Teachers lack ability to improvise	7	5	7	6	10
Teachers do not know methods	8	3	4	5	9
Not enough time given to science teaching	9	8	10	8	4
No community support	10	12	11	9	6
Teachers lack interest	11	9	9	10	13
No definite curriculum	12	13	12	11	12
Other subjects considered more important	13	11	13	12	11

ORGANIZING AND PLANNING FOR TEACHING ELEMENTARY SCIENCE

INTRODUCTION

The science program in the elementary school should be planned and structured, just as is done in the other areas of the elementary school curriculum. All too often elementary science programs have been either non-existent or else very loosely planned and structured. In such cases the elementary science textbook would usually serve both as science program and curriculum guide for the teachers. Sometimes a school system would list the science topics and concepts to be learned for each grade and include a number of suggested activities for teaching these topics and concepts.

In recent years there has been a steadily increasing trend to planned, structured programs, developed cooperatively by the teachers with the help of administrators and science supervisors, educators, and specialists. When planning such programs the first step invariably consists of identifying and clearly delineating the objectives, or goals, of science teaching.

The objectives of science education have changed very little in the past twenty-five years. The same objectives apply to both the secondary and the elementary school, the only difference being one of depth and degree of attainment. Although the literature lists a wide variety of objectives, they all fall into two categories those that pertain to the structure of science and those that pertain to the process of science.

The structure of science refers to science content. An effective science program aims for the acquisition of concepts and principles. There is no rote memorization of facts or laws, but the learning through appropriate techniques of concepts which lead to an understanding of conceptual schemes.

The process of science is a comparatively recent term in science education. However, its frame of reference is not new. It refers to the key

operations, or processes, of science and the scientist. In earlier years such terms as "ways of the scientist" and "desirable behaviors" have been used in the same context as process. They all refer to the methods of science that make it possible for children to learn science. These include all those abilities, skills, and attitudes that make critical thinking and problem-solving possible. In an effective science program great emphasis is placed upon process, because process is the means whereby real learning of the structure, or content, of science takes place in the classroom.

The elementary science program should be organized and structured so that it has adequate scope. The science topics that make up the program should be chosen with quality in mind, rather than quantity. The program should have balance, so that the child is given the opportunity to explore in the area of biological, physical, and earth science.

The program should have a well-developed sequence. The sequence should be such that the same science topics will be taken up not at successive grade levels but at alternate grade levels. This creates a spiral of fewer topics per grade, but allows the topics to be taken up in much greater depth than would be possible if a large number of topics were assigned to each grade.

Existing research on the mental, physical, and emotional behavior of children should be used as a guide in the development and grade placement of science units. Consideration should be given to the children's intellectual capacity, their ability to think abstractly, their curiosity, their aptitude for originality and creativity, and their span of attention and persistence.

A well-planned and well-organized science program should make proper provision for needed supplies, equipment, and reference materials. Also, an adequate amount of time per day should be allocated for the teaching of science. All too often the science lesson is the first to be dropped when other classroom activities run overly long. Finally, the science program should be in a process of continual evaluation if it is to retain its effectiveness.

SCIENCE EDUCATION FOR CHANGING TIMES*

National Society for the Study of Education

The following is an excerpt from Chapter Two of the Fifty-ninth Yearbook, Part I, of the National Society for the Study of Education, Rethinking Science Education. It shows how little the objectives of science education have changed since they were stated in the Society's Forty-sixth Yearbook. These objectives included the development of such learning outcomes as (1) functional information, concepts, and principles; (2) instrumental and problem-solving skills; (3) attitudes; (4) appreciations; and (5) interests. In the Fifty-ninth Yearbook, such terms as "critical thinking," "scientific process," and "inquiry" are introduced, and greater emphasis is placed upon those aspects of science that deal with these terms. Members of the committee who wrote Chapter Two include Paul DeH. Hurd, Vernon E. Anderson, J. W. Buchta, John H. Fisher, Eric M. Rogers, Guy Suits, and Ralph W. Tyler.

The objectives of science-teaching as they appear in educational literature have changed little in the past twenty-five years. On the other hand, there have been changes in the nature of the science taught; for example, the sciences have become more unified and have gained an important position in world affairs. These factors suggest the need to re-think the purposes of teaching science in schools.

Recently there has been much criticism of science-teaching. Some scientists have been concerned that science was not being taught either as understanding or as enterprise. They have thought that science-teaching should reflect the nature of science, and it should harmonize with the scientific point of view. The lack of social orientation in science-teaching and the failure to teach modern science have concerned other groups.

The objectives of the teaching of science are essentially the same from the elementary through the high school. The degree of attainment and the level of competency vary according to the development, interest, and abilities of young people. We cannot expect that every objective will be achieved by all students, that the rate of achievement will be uniform, or that everyone will reach the same level of understanding. This suggests

* REPRINTED FROM *Rethinking Science Education*, 59th Yearbook of the National Society for the Study of Education, Part I (Chicago: University of Chicago Press, 1960), pp. 33-37, by permission of the publisher.

that the objectives of the student who is oriented to a science career and those of the college-bound student will be different from those of other pupils.

Many criticisms directed toward the objectives of science-teaching are actually a censure of classroom procedures which fail to realize those objectives; for example, methods which demand too many facts, too little conceptualizing, too much memorizing, and too little thinking.

The following list of objectives provides a model by which the teacher may orient his thinking in developing his own purposes for teaching science.

UNDERSTANDING SCIENCE

There are two major aspects of science-teaching: one is knowledge, and the other is enterprise. From science courses, pupils should acquire a useful command of science concepts and principles. Science is more than a collection of isolated and assorted facts; to be meaningful and valuable, they must be woven into generalized concepts. A student should learn something about the character of scientific knowledge, how it has been developed, and how it is used. He must see that knowledge has a certain dynamic quality and that it is quite likely to shift in meaning and status with time.

The pupil needs at each grade level to acquire a background of ordered knowledge, to develop an adequate vocabulary in science for effective communication, and to learn some facts because they are important in everyday living, such as knowledge that is useful in maintaining health, promoting safety, and interpreting the immediate environment.

Recent theories and new knowledge should have priority in science-teaching when they are significant and can be made understandable at a specified grade level. The generalized concepts selected for teaching should be those which tend to explain or involve many science facts.

PROBLEM-SOLVING

Science is a process in which observations and their interpretations are used to develop new concepts, to extend our understanding of the world, to suggest new areas for exploration, and to provide some predictions about the future. It is focused upon inquiry and subsequent action.

Methods for solving problems in science are numerous. There is no one scientific method; in fact, there are almost as many methods as there are scientists and problems to be solved. Inevitably the details of scientific investigation are seldom the same for any two problems. What is done is highly flexible and quite personal. Incentive, intuition, the play of imagination, fertility of ideas, and creativeness in testing hypotheses are

important parts of the process. The methods of science are something more than measurement, laboratory techniques, and data processing followed by logical deductions. Sometimes they are not very logical, but the search for truth is always present. Presenting problem-solving as a series of logically ordered steps is simply a technique to isolate the critical skills and abilities and to give them special attention in teaching.

A process of inquiry involves careful observing, seeking the most reliable data, and then using rational processes to give order to the data and to suggest possible conclusions or further research. At higher levels of achievement the student should be able to establish relationships from his findings, and in turn to make predictions about future observations.

THE SOCIAL ASPECTS OF SCIENCE

Young people need to understand the dependence of our society upon scientific and technological achievement and to realize that science is a basic part of modern living. The scientific process and the knowledge produced cannot be assumed to be ends in themselves except for the classical scientist. For him the pursuit of new knowledge is a professional effort, and any lack of social concern on his part may be accepted. But a liberal education has a wider orientation, particularly at precollege levels. A student should understand the relation of basic research to applied research, and the interplay of technological innovations and human affairs. More of technology than science will be involved in social decisions; both are important in public policy.

APPRECIATIONS

A student with a liberal education in science should be able to appreciate:

1. The importance of science for understanding the modern world.
2. The methods and procedures of science for their value in discovering new knowledge and extending the meaning of previously developed ideas.
3. The men who add to the storehouse of knowledge.
4. The intellectual satisfaction to be gained from the pursuit of science either as a scientist or as a layman.

ATTITUDES

The knowledge and methods of science are of little importance if there is no disposition to use them appropriately. Open-mindedness, a desire for accurate knowledge, confidence in the procedures for seeking knowledge

and the expectation that the solution of problems will come through the use of verified knowledge, these are among the "scientific attitudes."

To understand the scientist is also to understand some of his attitudes, such as the desire to know and to discover, a curiosity about the world, the excitement of discovery, and the desire to be creative.

CAREERS

Science instruction should acquaint students with career possibilities in technical fields and in science-teaching. A continuous effort should be made to identify and motivate those who develop special interests. They should be given opportunities for some direct experience of a professional nature and a perspective of the fields of science.

ABILITIES

Science as a field of study is characterized by a moving frontier and an ever increasing amount of knowledge. Young people need to acquire those skills and abilities which will enable them to assume responsibility for expanding their own learning. Some of these skills and abilities are:

1. Reading and interpreting science writings.
2. Locating authoritative sources of science information.
3. Performing suitable experiments for testing ideas.
4. Using the tools and techniques of science.
5. Recognizing the pertinency and adequacy of data.
6. Making valid inferences and predictions from data.
7. Recognizing and evaluating assumptions underlying techniques and processes used in solving problems.
8. Expressing ideas qualitatively and quantitatively.
9. Using the knowledge of science for responsible social action.
10. Seeking new relationships and ideas from known facts and concepts.

FORMULATING OBJECTIVES FOR ELEMENTARY SCIENCE*

Ronald D. Anderson

Ronald D. Anderson recommends that, when formulating objectives, provision must be made for instruction in and evaluation of all the important outcomes of science instruction. All objectives can be classified into three domains: (1) cognitive, (2) affective, and (3) psychomotor. The objectives should be behavioral, and should be stated in terms of the specific behaviors which will be exhibited by the children. Also, the objectives should be dynamic, not static.

THE KEY TO GOOD EVALUATION

The objectives of an instructional program and the program's evaluation are intimately related. Without well-stated objectives there is no basis for making any judgment as to whether or not the program has achieved the desired goals (objectives). Before examining evaluation practices and procedures, it is first necessary for us, as teachers, to be sure we have a set of objectives which is an adequate basis for our evaluation. In this first of a series of two articles on evaluation, attention will be centered on the formulation of such objectives.

Stated objectives for elementary school science, as well as other parts of the curriculum, are found in abundance in textbooks, curriculum guides, and courses of study. In most cases, however, they are so general and vague that they are of little help to the classroom teacher either in determining what he will do in teaching science to his children at 10:25 AM, Tuesday, or in evaluating the success of his efforts. For example, a frequently identified objective in science is that children should develop problem-solving skills. Although it is agreed that this is a worthwhile and important objective of science instruction, it is so general and vague that it is of little worth to a teacher in determining specifically what he will do with the children. Also this vagueness makes it almost impossible to determine at the end of a unit whether or not the objective has been achieved. In sharp contrast to the above-mentioned objective is this specific one concerning observation and classification: Each child will be

* REPRINTED FROM *Science and Children*, Vol. 5, No. 1, September 1967, pp. 20-23. Copyright, 1967, by the National Science Teachers Association, Washington, D.C. Reprinted by permission of the author and the publisher. Dr. Anderson is Associate Professor of Education at the University of Colorado.

able to separate a group of twelve different leaves into four groups according to their size and shape.

At this point some readers are probably asking, "Why be so specific?" The answer is simple. Unless an objective is stated precisely, it is not clear what steps should be taken to achieve the objective. Some teachers teach science only because it is part of the school program or because it has always been taught in their school. They have not stopped to consider carefully *why* science is taught. Whereas, the reasons why science is part of the curriculum determine what aspects of science will be emphasized, what approach will be used, and what objectives will be realized. Without clearly defined reasons, which in turn determine the objectives, teachers have no basis for deciding the questions of "what aspects" and "how." A broad objective such as "to develop problem-solving ability" may be a good starting point but it must be broken down into a more detailed description before decisions are made about "what aspects" and "how" for classroom use. In the grouping of leaves activity, the broad objective has not been rejected, only stated in much greater detail, i.e., classifying objects is part of solving some problems.

Basically, science is included in the curriculum because it is such a large and influential part of our culture. Of course, science is much more than a body of knowledge about the material universe. To understand science, one must understand the process of science (the means of investigation by which the body of knowledge is acquired) as well as the products of science (the body of knowledge that results from the investigations). Since a basic objective is for children to understand science, our specific objectives for each unit or day should reflect this basic and far-reaching objective. The precise objectives that are formulated for each class period should reflect the fact that a basic and overriding objective is that children will acquire an understanding of both the products and processes of the scientific enterprise.

MAKE PROVISION FOR ALL OBJECTIVES

A basic consideration in preparing objectives is that provision must be made for instruction in and evaluation of all the important desired outcomes of science instruction. The stated objectives which serve as the basis for instruction and evaluation should reflect all of the desired outcomes. A brief look at a classification of educational objectives might be useful in determining if the objectives are limited and unimaginative. Such a classification is Bloom's *Taxonomy of Educational Objectives*.¹ In this scheme, all objectives have been classified into one of three

¹ Bloom, Benjamin S., Editor. *Taxonomy of Educational Objectives, The Classification of Educational Goals, Handbook I: Cognitive Domain*. David McKay Company, Inc., New York City. 1956.

"domains"—*cognitive, affective, and psychomotor*. The objectives which are generally given most attention by the teacher of elementary science fall within the cognitive domain which includes the recognition and recall of information and also the development of various intellectual abilities. Many of the objectives which are included in textbooks and curriculum guides, but to which teachers less often direct their teaching, are part of the affective domain. These pertain to the development of attitudes, values, interest, and appreciation. Physical, manipulative, and motor abilities are part of the psychomotor domain.

Since the cognitive domain receives most attention, it will be examined here in greater detail. A look at the various levels of this domain will give some insight into the level of sophistication of objectives.

The first and lowest level in the cognitive domain is the *knowledge* level. It includes the recall of specifics (e.g. ice is a form of water), structures (e.g. the skeletal structure of vertebrates), or scientific processes (e.g. a control is an important part of an experiment). The knowledge level emphasizes that which would be described as remembering. Of course, the examples given here could be understood at a deeper level. They are classified at this level if it is only a matter of being able to remember the information rather than a deeper understanding such as being able to apply it to a new situation or synthesizing several items of knowledge. These deeper understandings are dealt with in other levels of this classification system. The entire taxonomy is a hierarchy in which each lower level of understanding is necessary before understanding at the next higher level is possible.

The second level is *comprehension* which includes translation from one form to another. Examples would be drawing a graph of daily temperature changes from a list of temperatures recorded over a period of days or weeks, or explaining verbally what is meant by a statement which is expressed in mathematical symbols.

Application, which is the third level, requires the ability to apply abstract ideas in a concrete situation. Examples would be the ability to use a knowledge of the relationship between heat and the expansion and contraction of liquids to explain how a thermometer works, use a knowledge of classification to classify a group of seashells according to size, shape, or color, or use a knowledge of electric circuits to cause a light bulb to light using a cell, bulb, and pieces of wire.

Analysis, the fourth level, involves breaking down an idea into its various parts and determining the relationship between the parts. Determining which statements about an experiment are facts and which are hypotheses, or determining which factors led to an unexpected conclusion of any experiment would be examples.

Synthesis, the fifth level, includes taking parts and putting them together to form a whole such as skill in expressing verbally or in writing the results of an experiment using an appropriate organization of ideas.

Other examples would be formulating a hypothesis to explain why some animals are less active in the daytime than at night or why water poured on a fire will often put out the fire.

Evaluation, the highest of the six levels in the cognitive domain, includes making judgments. An example is the ability to state the fallacies in an analysis of an experiment. Another example is the ability to evaluate popular beliefs about health.

The reason for looking at this classification of objectives is to gain some insight into the sophistication of the objectives we actually are endeavoring to reach in our teaching. Is teaching aimed at the remembering of facts and ideas or are children expected to be able to apply these facts and ideas? Do some children arrive at junior high school without having been challenged to analyze, synthesize, or evaluate ideas? Do the children gain a greater interest in science or a better appreciation of its place in society? If this classification of objectives has caused the readers to think critically about the objectives of their science program, it has served the purpose for which it was included here.

OBJECTIVES SHOULD BE BEHAVIORAL

So far, it has been pointed out that objectives should be specific, in keeping with the area of study at hand, and not be limited to the knowledge level. In addition, objectives should be stated in a manner that permits a judgment about the attainment of the objectives. To make this possible, objectives should be stated in terms of the behaviors which will be exhibited by the children. Objectives stated in this form are often spoken of as behavioral objectives or performance objectives. Behavioral objectives have been talked about for years, but recently they have received renewed and closer attention. For example, *Preparing Instructional Objectives*, a small book by Mager,² is devoted entirely to the "how" of writing good behavioral objectives. *Science—A Process Approach*,³ the experimental elementary science program sponsored by the American Association for the Advancement of Science, has behavioral objectives set up for each lesson in the program. In addition to providing a basis for the teacher's efforts in aiding student learning, the behavioral objectives provide the basis for the extensive evaluation which is being conducted by the sponsors of the program.

In order to understand what is meant by a behavioral objective, let us look at some of the basic ideas presented by Mager. First of all, an appropriate objective is *not* a description of what the lesson is about, but

² Mager, Robert F. *Preparing Instructional Objectives*. Fearon Publishers, Palo Alto, California. 1962.

³ *Science—A Process Approach*. American Association for the Advancement of Science, Washington, D.C. 1966.

is a statement of what the learner will be able to *DO* at the end of the learning activity. For example, "a study of the kinds of materials that are attracted by magnets" is a description of what is to be included in a certain science lesson. It is not an objective. In contrast, although in some ways incomplete, the following is an objective: "At the conclusion of this lesson the children will be able to state what kinds of materials are attracted by magnets." It describes what the children will be able to do. Thus, the first step in formulating good behavioral objectives is deciding what the child should be *DOING* when the instruction has been successful.

A key to writing good objectives is the verb which describes what the child will be able to do. Some are vague and open to many interpretations. Others have clarity and convey a definite meaning. Consider carefully the chart of examples from Mager⁴ on the opposite page:

*Words Open to Many
Interpretations*

to know
to understand
to *really* understand
to appreciate
to fully appreciate
to grasp the significance of
to enjoy
to believe
to have faith in

*Words Open to Fewer
Interpretations*

to write
to recite
to identify
to differentiate
to solve
to construct
to list
to compare
to contrast

There is nothing wrong with teaching children to "understand" and "enjoy," but clear communication of ideas requires that objectives be stated in terms of what they will be *DOING* that indicates they "understand" or "enjoy." How else will teachers know if children are "understanding" or "enjoying?"

After determining what behaviors are the object of instruction, a second major question can be considered: Under what conditions will these behaviors be observed? The answer to the question will progress one step further toward a precisely stated performance objective. Consider this objective: At the end of this lesson, the child should be able to identify constellations in the night sky. Does it state the conditions under which the objective is to be reached?

It does not indicate whether the child is expected to make the identification with or without the aid of a star chart or other reference. It does not state whether the student is given a list of the names and asked to assign these names to the appropriate constellation or whether the

⁴ Mager, *Op. cit.*, p. 11.

student is expected to produce the names from memory. Therefore, the objective should be restated.

A third major question that should be considered in formulating performance objectives is "How well is the child expected to perform?" or "What is the minimum acceptable level of performance?" Look again at the objective above on identifying constellations in the night sky. Is the objective stated in such a way that this kind of question is answered? It does not tell *how many* constellations the child is expected to identify. Also, in the case of some objectives, it may be desirable to indicate *how long* the child has to attain the objective.

Now the objective concerning identification of constellations can be restated in a more precise form: At the end of this lesson the child should be able to identify at least five constellations when given a star chart as a guide. This objective answers the three basic questions: What is the behavior? What are the conditions? and What is the minimum acceptable level of performance?

CAN OBJECTIVES BE MADE BEHAVIORAL?

Readers are no doubt asking "Can all of our objectives be stated in behavioral form with the conditions and minimum level of performance clearly indicated?" It may not always be easy. For example, a common objective of science education is the development of interest in science. It must be asked what behaviors on the part of the child will indicate that this interest is present. Would behaviors such as reading books on science, visiting a local science museum, or building a simple telescope for observing the stars and planets be indicators of this interest? Difficulties may be encountered in giving the *conditions* and *minimum level* of performance for such an objective, but the objectives can be framed in terms that will allow teachers to make judgments on the basis of student performance. A teacher's objective might be: the child will pursue his interest in astronomy by such means as, reading library books on astronomy, visiting the local museum, and making night-sky observations.

As another example, there is certainly a place in the elementary school science curriculum for free exploration on the part of children, such as "playing around" with magnets in an undirected fashion or observing mealworms for an extended period of time without definite directions concerning what they should observe. Such activities often lead to the posing of interesting questions and interesting hypotheses that might answer the questions as well as creating means of testing hypotheses. Objectives for such activities should reflect *why* the children are being encouraged in this direction. Objectives might be: by the end of the class the child will have posed two or more questions concerning magnets, or by the end of the class the child will have posed two or more hypotheses as possible answers to questions concerning the behavior of mealworms, or the child will design an experiment for testing a hypothesis concerning the

behavior of mealworms. Here again, there may be some difficulties stating conditions and minimum levels, but the children's behavior can be used as the referent in determining if the activity was worthwhile. It must be granted that educators cannot always state their objectives as precisely as they would like, but they can certainly do better than they often have done in the past.

Objectives are dynamic not static. They are based on more than the structure of the subject and thus they change as a result of experience with children in the classroom. The teacher may find that an object is not realistic in view of the level of maturity of the children or classroom experience may suggest a different objective which is more profitable to pursue than the one originally stated. It is necessary to begin by carefully specifying objectives, but to be flexible enough to alter them as experience indicates. Careful stating of objectives provides an aid to the clear thinking and planning which must continue throughout the duration of the science instruction.

This article has been concerned with the formulation of objectives for the elementary school science curriculum. After they are formulated, the next step is to teach to attain these objectives. That is the job of the reader.

THE DEVELOPMENT OF SCIENTIFIC ATTITUDES*

Richard E. Haney

Although considerable emphasis has been placed recently on the teaching of inquiry skills, manipulative skills, and science knowledge, Richard E. Haney sees the need to re-focus attention on the learning of scientific attitudes. He discusses the following attitudes which directly govern the intellectual behavior of scientists and science students: curiosity, rationality, suspended judgment, open-mindedness, critical-mindedness, objectivity, honesty, and humility. These attitudes must be planned for and not simply accepted as concomitants to cognitive outcomes. Eight steps are suggested that teachers can take to facilitate the learning of attitudes.

* REPRINTED FROM *The Science Teacher*, Vol. 31, No. 8, December 1964, pp. 33-35. Copyright, 1964, by the National Science Teachers Association, Washington, D.C. Reprinted by permission of the author and the publisher. Dr. Haney is Associate Professor of Education at the University of Wisconsin, Milwaukee.

In the last few years considerable emphasis has been placed on the teaching of inquiry skills as well as on useful knowledge and manipulative skills. Some mention has been made of scientific attitudes, to be sure, but these still remain inconsistently defined in the literature and obscure in teaching plans. Daily lessons tend to center around some conceptual theme, a major principle, or some other form of cognitive learning outcome while affective learnings at best are considered peripheral to this central idea.

The habits of thought associated with scientific thinking deserve more careful consideration. Problem-solving skills are essentially amoral. Knowledge and intellectual prowess divorced from the controlling influence of desirable attitudes toward man and nature contribute to the phenomenon which Robert Cohen termed the "frustration of humane living inherent in science of the twentieth century." (2) Science supposedly molds the character of its practitioners. To be scientific means that one has such attitudes as curiosity, rationality, suspended judgment, open-mindedness, critical-mindedness, objectivity, honesty, and humility.

Science lessons present many opportunities for teachers to help pupils develop these attitudes, which also have value outside the classroom and in other areas of human experience. Let us then consider the nature of attitudes, examine these eight attitudes and the overt behavior governed by them, and suggest appropriate learning experiences.

One of the most frequently quoted definitions of attitudes is the statement by Allport in which an attitude is described as a "mental and neural state of readiness, organized through experience, exerting a directive or dynamic influence upon the individual's response to all objects and situations with which it is related." (1) Sells and Frites point out that such mental and neural states cannot be observed directly in students. "An attitude is a psychological construct, or latent variable, inferred from observable responses to stimuli, which is assumed to mediate consistency and covariation among these responses." (6) Attitudes regulate behavior that is directed toward or away from some object or situation or group of objects or situations. Attitudes have emotional content and vary in intensity and generality according to the range of objects or situations over which they apply. For the most part, attitudes are learned and are difficult to distinguish from such affective attributes of personality as interests, appreciations, likes, dislikes, opinions, values, ideals, and character traits.

GUIDES TO SCIENTIFIC BEHAVIOR

A recent attempt to analyze the process through which attitudes are acquired appears in the *Taxonomy of Educational Objectives, Handbook II: Affective Domain*. Attitudes are said to emerge first at the level of "willingness to respond" and become increasingly internalized in the

learner through the stages of "satisfaction in response," "acceptance of a value," "preference for a value," "commitment," and "conceptualization of a value." At this last stage the learner is able to "see how the value relates to those that he already holds or to new ones that he is coming to hold." (4)

The first attitude to be considered is *curiosity*. This is the desire for understanding on the part of the student when confronted by a novel situation which he cannot explain in terms of his existing knowledge. A curious person asks questions, reads to find information, and readily initiates and carries out investigations. Curiosity is a stimulus to inquiry, and it is a desirable outcome of instruction as well. Each discovery raises new questions and suggests new undertakings. Pupils should leave science courses with greater curiosity than they had at the outset. But, who are the most curious? Usually they are the younger children. Somehow our pupils manage to lose the spirit of inquiry with advancing age. Each teacher must ask himself how he can teach for heightened curiosity. Curiosity is learned. It can be learned or repressed in the classroom. Problematic situations in which answers and explanations are not immediately available help to stimulate curiosity. The solutions of problems should raise new problems.

While curiosity stimulates inquiry, the attitude of *rationality* guides the scientist's behavior throughout his investigation. This is the habit of looking for natural causes for natural events. The rational person is not superstitious. The prescientific period in our history was marked by numerous examples of mythological explanations. This tradition still abounds in our folklore and in the everyday thinking of many persons. To help them develop the attitude of rationality, pupils can be confronted with situations in which careful reasoning proves superior to explanations of a superstitious nature.

Willingness to suspend judgment is another attribute of personality fundamental to scientific behavior. Persons with this attitude accumulate sufficient evidence before making judgments or drawing conclusions. They recognize the tentative nature of hypotheses and the revisionary character of our knowledge. To learn the attitude of suspended judgment, our students should be confronted with situations in which this behavior is rewarded or in some way leads to success while formation of conclusions without evidence leads to failure. Pupils should examine explicitly the consequences of jumping to conclusions.

Science teachers ought to examine closely the common practice of asking students to formulate a conclusion at the end of every five-minute demonstration or forty-minute experiment. These activities concern but a limited sample of all the phenomena governed by the principle under consideration. At the end of these experiences students should have the opportunity to choose among formulating a generalization with various qualifications, stating that they have only learned something about the

particular operation at hand, or stating that they could make no sense of the data.

ACCEPTANCE OF NEW IDEAS

Open-mindedness is closely akin to suspended judgment. To comprehend science as the human enterprise that it is, our future citizens must learn from experience that our ideas of what is true may change. They must be able to revise their opinions or conclusions in the light of new evidence. Experiences that foster open-mindedness include those in which pupils are confronted with the need to revise a belief as the result of having acquired new information on the subject.

The willingness to consider novel hypotheses and explanations and to attempt unorthodox procedures is a form of open-mindedness toward creative ideas which amounts to the "no holds barred" attitude of the scientist. The scientific method is not simply the application of routine and predetermined procedures to new problems. The study of new areas of knowledge often requires the invention of new methods of inquiry. Popular conceptions and explanations may fail to fit new bits of evidence. The history of science contains the stories of men who broke with traditions and saw nature in a new light. To foster this creative spirit in the classroom, teachers can provide experiences in which pupils have the opportunity to design their own investigations and invent and evaluate their own explanations for natural phenomena.

New ideas are not accepted in science simply because they are new or different. To be scientific also means to be *critically minded*. A person with this attitude looks for evidence and arguments that support other persons' assertions. He challenges authority with the questions "How do you know?" and "Why do we believe?" He is concerned about the sources of his knowledge. One of the greatest temptations confronting the science teacher is that of giving direct answers to children's questions and of offering glib explanations. Teachers need to be careful of answers that include the word "because." Most explanations are not as simple as they might possibly appear at first.

How must teachers behave if their students are to learn the attitude of critical-mindedness? How often do they encourage their students to ask in class "How do you know?" To foster the learning of this attitude, teachers should provide evidence to support the generalizations in the lessons. Pupils should be taught to look for arguments and evidence supporting important propositions, and they should be taught to provide these in their own communications. The reading of historical and biographical accounts of investigations are also valuable experiences from which pupils can learn of the sources of our current knowledge.

The scientist must also be *objective* in gathering and interpreting his data and intellectually *honest* in communicating his findings. To learn the

attitude of objectivity, students may be confronted by situations in which the temptation to permit personal feelings to interfere with the recording of an observation or the interpretation of data must be successfully resisted in order to achieve a correct or accurate solution of a problem. Complete objectivity is difficult to achieve because an observer's perceptions are governed by his previous experiences and his expectations.

Intellectual honesty, on the other hand, is concerned with the conscious act of truthfully reporting observations. Teachers have to ask themselves how they reward honesty in their classrooms. In the laboratory, for instance, do the pupils know the *right* answers to report regardless of their actual sense data? The value of open-ended experiences for instructional purposes is that they are more like those of the scientist at the frontier of knowledge where the answers are not yet known. Science could not be the cumulative enterprise that it is if it were not for the objectivity and honesty of its practitioners.

PERSONAL VIEW OF WORLD

The foregoing attitudes directly govern the intellectual behavior of scientists and science students. To be "scientific" means to have these personality traits. In our classrooms, however, children learn more than the content and processes of science. They incorporate these bits of knowledge and skills along with those gained in other subjects and extracurricular experiences into their personal views of the world and their places in it. Each student gradually builds his own philosophy of life.

Humility is a desirable ingredient of the mature personality. It can be learned, at least in part, as a result of science instruction. Science can teach children to recognize their own limitations as well as the limitations of science itself. This is the attitude that underlies the conservation movement. It is the humble person who uses natural resources wisely, for the common good, even though he might have to forego immediate gains that could accrue from their exploitation.

RELATIONSHIP TO NATURE

On the other hand, man's relationship to nature is more than a matter of "wise use." He shares this world with other beings whose "rights" deserve to be recognized. The history of science and also of religion is a story of man's struggle with his own egocentrism. The message that Rachel Carson gave us in *Silent Spring* relates a current episode in that story. Albert Schweitzer has expressed the attitude of humility in terms of "reverence for life" which identifies the moral principle that the good consists in the preservation, enhancement, and exaltation of life, and that destruction, injury, and retardation of life are evil. The world presents a

spectacle of "will-to-live" contending against itself. One organism asserts itself at the expense of another. Man can only preserve his own life at the cost of taking lives. One who holds to the ethic of reverence for life injures or destroys only out of necessity. Never does such a person kill other beings from thoughtlessness. (5) There is a curious similarity in the messages of Rachel Carson, the scientist, and Albert Schweitzer, the theologian.

What sort of humility or reverence for life is taught in our biology classes? The trend, at present, is to increase the amount of experimentation with living materials in order to make the work of the student more like that of the scientist. But, perhaps, we have in "reverence for life" a limitation to the discovery method of teaching. What attitudes do the students learn if animals are dissected merely to show that the chart on the wall or the plastic model on the demonstration table is correct? What concern for other lives is taught if an anesthetized rat is cut open so that the students can experiment with the heart of a dying animal? Such activities are likely to reaffirm the attitude that all of creation belongs to man to be plucked, manipulated, harvested, or controlled at his will for purposes *he* considers essential. To teach the attitude of reverence for life, it may be that vicarious experiences will have to be employed to a great extent, even though to do so would be to compromise the principle of making learning experiences as much like those of the scientist as possible.

TO FOSTER ATTITUDE BUILDING

The attitudes which have been explored are attributes of intellectually and emotionally mature individuals, persons who do not only behave outwardly in desirable ways but who understand why they act as they do. If these and other attitudes are to be fostered, they must be planned for and not simply accepted as concomitants to cognitive outcomes. Klausmeier suggests eight steps that teachers can take to facilitate the learning of attitudes. (3) These may be interpreted in terms of the problems of science teaching in the following manner:

1. The attitude to be taught must be identified. Examples of attitudes related to science have been identified in this article.
2. The meanings of the vocabulary used to describe attitudes or the behaviors related to them must be clarified for the learner.
3. Informative experience about the attitude "object" should be provided. In the case of scientific attitudes these "objects" are usually the various situations that occur in the problem-solving process. Typical of these are (a) the sensing of the problem in a perplexing situation, (b) clarifying and defining the problem, (c) formulating of hypotheses, (d) reasoning out the consequences of the hypotheses and the designing of investigations, (e) gathering of data, (f) treating

and interpreting of data, (g) generalizing or drawing conclusions, and (h) communicating the results of the investigation to others. Students need to be instructed in the performance of each of these steps and in their relationships to the various attitudes that characterize the scientifically minded person. It is hoped, of course, that pupils will exhibit these attitudes in appropriate situations outside the classroom. To help them generalize these attitudes, teachers can point out the general nature of the attitude object by showing similarities between scientific problem-solving procedures and the treatment of problematic situations in daily affairs.

4. Desirable identifying figures for the learner should be provided. These models, whether they be teachers, parents, peers, or historical figures, provide the learner with ready-made behaviors which he can use as his first attempts at the desired behavior.
5. Pleasant emotional experiences should accompany the learning of the attitudes. Pupils need freedom to attempt their own patterns of exploration and sufficient time to pursue an investigation to the point where they experience the satisfaction that accompanies inquiry and discovery.
6. Appropriate contexts for practice and confirmation should be arranged. Learning experiences must be selected on the basis of knowledge, skills, and attitudes to be learned. At times the central theme of a lesson might have to be a particular attitude with other learnings playing secondary roles.
7. Group techniques should be used to facilitate understanding and acceptance. The varied activities possible in well-equipped science rooms permit students to learn as individuals on some occasions and as members of groups of varying sizes on others. Group decision making that occurs in the planning and carrying out of investigations and the evaluation of results permits a sharing of emotional commitment which can enhance the learning of an attitude.
8. Deliberate cultivation of the desired attitude should also be encouraged. Pupils need to be aware of the behaviors that accompany an attitude and to practice them. Sometimes this requires the difficult task of breaking old habits or of improving poorly learned ones. The teacher must be able to provide guidance for this learning.

There are implications in what has been said for the education of teachers as well as for the instruction of schoolchildren. It has often been said that "you can't teach something you don't know." A corollary to this generalization might be this: "Pupils cannot learn attitudes that their teachers don't have." It may very well be that the first step in meeting this challenge to science education will consist of an inward look upon our own knowledge and value systems. Science teachers have a responsibility. It is to them that the public turns for an understanding of science, not just

the facts of science, or the skills, but also for a perspective that relates science to all other areas of human experience.

References

1. Gordon Allport. "Attitudes." Chapter 17 in *Handbook of Social Psychology*, C. Murchison, Editor. Clark University Press, 1935. p. 806. Quoted in *Children's Thinking* by David Russell. Ginn and Company, Boston, Massachusetts, 1956. p. 170.
2. Robert S. Cohen. "Individuality and Common Purpose: The Philosophy of Science." *The Science Teacher*, 31:27-33. May 1964, p. 31.
3. Herbert Klausmeier. *Learning and Human Abilities: Educational Psychology*. Harper & Row, Publishers, New York, 1961. p. 267.
4. David Krathwohl et al. *Taxonomy of Educational Objectives, Handbook II: Affective Domain*. David McKay Company, Inc., New York, 1964. p. 36.
5. Albert Schweitzer. *The Philosophy of Civilization*, translated by C. T. Carapian. The Macmillan Company, New York, 1959. pp. 307-329.
6. Saul Sells and David Trites. "Attitudes" in *Encyclopedia of Educational Research*. Chester Harris, Editor. The Macmillan Company, New York, 1960. p. 103.

PREREQUISITES OF AN EFFECTIVE ELEMENTARY SCIENCE PROGRAM*

Edward Victor

The following is a portion from Chapter 3, "The Elementary Science Program," of Science for the Elementary School. Edward Victor cites with precision the necessary prerequisites for an effective elementary science program. The program must be planned and structured. It should be a coordinated part of an overall K-12 science program, and correlated with the rest of the elementary curriculum. It should emphasize both the content and process of science. It should have scope and sequence, and a balance of content from all the sciences. There must be a variety of activities, provision for individual differences, provision for necessary materials, sufficient time, and help and encouragement for the teacher. Finally, the program must be evaluated continuously if it is to be an effective one.

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In recent years an increasing number of local science programs for the elementary school have been emerging. These programs are the result of cooperative efforts of classroom teachers, supervisors, administrators, and science specialists.

These new programs are rich in content and process, and provide for an abundance of learning activities. These activities are directed specifically at giving the children an opportunity to investigate and explore so that effective learning takes place and desirable behavioral outcomes emerge. Provision is made for all kinds of learners: slow, average, and fast. Teachers are supplied with source materials and with necessary equipment. Competent supervisors or specialists are available for assistance.

Science programs may vary somewhat in their science content, learning activities, and teaching or unit format. However, all programs should meet the following prerequisites, if they are to be effective and successful.

PLANNING

A science program should be planned. When science was first taught in the elementary school, and for some time thereafter, there was no such thing as a planned science program. Science learning was organized around incidents that occurred in the classroom. If a child brought a magnet, whistle, unusual-looking rock, queer insect, or pretty leaf into class, a lesson or unit in science was developed around the incident. Often the lesson was quite brief and ended the same day. Usually this kind of lesson tended to stress identification, nomenclature, and the learning of facts rather than major science concepts. If there were no incidents, there were often no lessons in science.

There is no question that incidents arising in the classroom can be a tremendous motivating experience for the children. Under the direction of experienced and skillful teachers with a good science background, such incidents can be used to produce excellent teaching and learning. However, incidents alone are not sufficient to ensure an adequate science program for the elementary school. Nor would the teachers even think of teaching other areas in the elementary curriculum solely on this basis.

One of the most significant forward trends in science education today is the general agreement that the science program should be planned and structured, just as the programs in the other areas of the elementary school curriculum are planned and structured. A planned program not only provides a steady progression of science learning in all grades, but also gives the teacher a definite background and framework of basic science information with which to work in the classroom.

A properly organized program will not discourage incidents that occur, but rather will welcome them as an additional means for producing more effective learning in the classroom. In fact, a planned program now makes

it possible for the teacher to create deliberately the kinds of incidents that will instill in the children a desire for exploration and investigation. And when unusual or important incidents do arise, such as sending a satellite or astronaut into space, the planned program can be flexible enough to provide time for these incidents to be taken up in detail.

A planned program should provide for and be guided by the interests of the children. An effective program takes into consideration the children's interests and uses them to motivate learning in science. At the same time it permits the children to help plan and carry out the daily and long-range work in science.

A COORDINATED PART OF A K-12 SCIENCE PROGRAM

Science in the elementary school should be planned and coordinated so that it is part of an overall K-12 science program. In this way haphazard teaching, unnecessary repetition, overlap, and flagrant omissions are eliminated. Instead, a steady progression of learning takes place at each grade level, building upon knowledge from previous grades and leading to further knowledge in the following grades. The science content to be learned will proceed steadily from the very simple to the abstract, as the children grow in maturity. At the same time, the children will become progressively more proficient in the process of science, proceeding from the simpler to the more complex operations of science and the scientist. In addition, the children will gradually acquire experience in solving problems and in thinking critically and creatively.

CORRELATION WITH THE ELEMENTARY CURRICULUM

The correlation of the science program with the rest of the elementary curriculum has already been discussed in detail in Chapter 1, under the broad goals for the elementary science program, as well as earlier in this chapter, when possible guides to be used in selecting science content for the science program were suggested. Care should be taken, however, when correlating science with the rest of the curriculum, that the learning of science is not lost in the process. Real science learning cannot take place in a combined social studies-science unit on "Communications," when teachers take up the social aspects in great detail and merely talk about the science portion. Moreover, although it is good educational practice to correlate science when possible with the rest of the curriculum, it is also impractical and unwise to insist that all science be integrated with other areas. There are many phases of science that are learned best alone. Also, there are times where it is more logical to integrate the other areas with science rather than integrate science with the other areas.

SCOPE AND SEQUENCE

The science program should have scope and sequence. *Scope* refers to the content in the program, and *sequence* refers to the grade level or levels where the content will be allocated. The science program should be broad in scope so that the children will have ample opportunity to learn major concepts and basic principles that affect all the principal aspects of their environment. These broad understandings should be drawn from all areas of science, and their introduction should begin as early as kindergarten, then be developed and expanded through the elementary grades. This will help enable the children to acquire a greater understanding of their environment, of how man strives to use and control his environment, of how living things adapt and adjust to their environment, and of how living things are or may be interdependent and interrelated.

An examination of the current elementary science textbooks and science programs shows a fair amount of agreement on the scope of science content to be taught in the elementary school. However, this agreement is not true of sequence. Both textbooks and science programs vary widely and consistently in their grade placement of science topics. Some research is being conducted to determine the age levels or grades where selected science topics or understandings can be taught successfully. The findings generally tend to show that children at any grade level can learn something about all areas of science, provided the concepts are within the children's level of maturity and comprehension.

It is becoming more obvious that any attempt to develop one universal science program with a rigid or fixed grade-placed sequence, is virtually impossible. Children can and do differ widely in ability between schools in the same community, and also between schools of different communities. It is not uncommon for a teacher to find that the children differ in ability from year to year even in the same grade.

Yet it is equally obvious that some kind of sequence is necessary. In every science topic the concepts range from the very simple to the more complex. Some topics involve concepts that are more abstract than others. Whatever topics are assigned to a lower grade level will contain concepts that cannot be developed fully, regardless of the children's ability. Further development of these concepts will be needed at a higher grade level to ensure complete comprehension and learning.

Earlier science programs attempted to solve the problem of sequence by requiring the same topics—such as Magnets or Sound—to be taught each year, with provision for a steady spiral of concepts to be developed in each grade, progressing from the easily understandable to the more difficult. When the topics were narrow and unrelated, the science programs proved to be highly unsatisfactory for everyone.

Most science programs today have abandoned this tight spiral of narrow topics and have adopted a much looser spiral pattern. This has been

accomplished by incorporating the individual topics under broader, related content areas. In this way, although a major area is taken up each year, an individual topic—such as sound or magnets—is taken up only periodically.

As a result, the grade placement of science topics in these programs varies, depending upon the basic philosophy of the different schools or school systems and upon the number of broad content areas that make up the program. Some schools organize their science content so that a topic is taken up three times during the kindergarten through grade 6 period: the sequence is as follows: once in grades K-2, a second time in grades 3-4, and a third time in grades 5-6. Other schools take up a science topic just twice: in grades K-3 and again in grades 4-6. Still other schools have no regular pattern, but will take up a topic two, three, or even four times, depending upon the amount of science content entailed in the topic.

Some schools assign specific science units to the kindergarten. Others suggest only that the kindergarten teacher scrutinize her daily program of activities closely for science implications, then plan accordingly for experiences in science. Still others provide for both planned science units and incidental activities arising from the questions that the children will ask.

Regardless of which grade-placement plan a program uses, in all cases individual topics are now taken up periodically from kindergarten through grade 6. This plan enables each topic to be explored in greater depth and more satisfying detail. As a result, not only is there a greater opportunity for more major understandings to emerge each time, but also relationships between these understandings can now develop more easily, in a number of ways and from more than one direction. Programs such as these make possible a real spiral of learning. When a topic recurs in a spiral, new and more difficult concepts are built upon previously learned concepts. In each case previous knowledge about the topic is reviewed briefly, and then this knowledge is extended further. Repetition thus serves to associate the old concepts with the new.

Exact grade placement of science content in the science program is usually an individual concern, left to the decision of those working with the program. The grade placement may vary from school to school within the same community, or from community to community. Most concepts allocated for a specific grade level can be learned with equal success in one grade level immediately above or below the specified grade. However, difficulties are more likely to arise when the difference in allocation of concepts involves two or more grade levels.

The following suggestions may be helpful in organizing the sequence of topics and concepts for a science program. To begin, many individual topics can be related and incorporated to form broader content areas. Magnetism, static electricity, and current electricity, for example, can be combined to constitute one content area. Similarly, machines can be

combined with friction, heat with fire and fuels, water with weather and climate, soil with rocks and minerals, and air with planes and space travel.

Some science topics might be placed in the same grade because they are all concerned with a common conceptual scheme. For example, an understanding of the theory of molecular motion will explain many of the phenomena of heat, sound, magnets, and physical states of matter. If the molecular theory is allocated to a certain grade level, the placement of these topics in the same grade level may save needless repetition and at the same time ensure a greater understanding of the theory because it was approached from different directions. Also, when the atomic theory is allocated to a certain grade, static and current electricity could also be profitably placed in the same grade.

Allocation of topics and concepts will also depend upon the children's growth in ability to understand cause-and-effect relationships, to recall and rationalize, and to grasp abstract ideas. In some programs the science for kindergarten through grade 2 is primarily devoted to making the children aware of science phenomena in their environment. Science in grades 3-4 is directed toward promoting the understanding of simple cause-and-effect relationships. In grades 5-6 the more complex or abstract concepts involved in the cause-and-effect relationships are developed. For example, in the first spiral the children may learn that water can disappear or go into the air, where it becomes an invisible gas called water vapor. In the second spiral the children will explore the factors that affect evaporation, such as heat, wind, surface area, and so on. In the third spiral the children will learn the molecular theory and how evaporation and the factors affecting evaporation can be explained according to the molecular theory. Thus the children develop awareness in the first spiral, deal more with the effects in the second spiral, and devote more time to the causes in the third spiral.

Finally, the science program should evaluate its sequence continuously, not periodically. Only if the effects of a particular sequence on learning in the classroom are carefully observed, and the sequence constantly reshuffled whenever the grade placement appears to be unsuited, can a well-organized and effectively structured science program emerge.

BALANCE

The science program should have balance. A well-balanced program should provide opportunities for the children to explore regularly in each of the three major areas, which include the earth and the universe, living things, and matter and energy. Equal emphasis should be given to the physical and the biological sciences in the overall program. A balance in the length of units might be desirable so that some would be long and others would be shorter. There should also be balance in the number of

units taught each year. The present trend is toward the adoption of a relatively small number of units per year, however, with provision for greater depth in science content.

EMPHASIS UPON CONCEPTS AND CONCEPTUAL SCHEMES

The science program should be concerned with more than technology. Too many science programs place undue emphasis upon how science helps us in our daily life, and not enough emphasis upon the underlying science concepts. The result is that the children, our future adult citizens, acquire a distorted image of science. They tend to view science primarily as an agent for developing useful gadgets and appliances, thus making their lives more pleasant and comfortable. The science program should provide children with ample opportunity to learn some of the key concepts and conceptual schemes that play such an important part in their daily lives, their environment, and the world in which they live.

EMPHASIS ON THE PROCESS OF SCIENCE

The science program should make the children aware that science is a way of life—an exciting process of inquiry that man uses to investigate, explore, discuss, and explain the natural phenomena of the world in which he lives. Consequently, wherever possible, the children should be given an opportunity to learn and gain proficiency in the use of the key operations of science and the scientist. They should be given practice in learning how to solve problems and how to think critically and creatively. As they perform these operations they will learn concepts and conceptual schemes, and they will develop such desirable behavioral outcomes as scientific skills, attitudes, appreciations, and interests.

VARIETY OF ACTIVITIES

The children should have ample opportunity to use a large number of diversified activities when learning science. Some children seem to learn better or more easily from one kind of activity than another. They should have a chance to do experiments and demonstrations, read, give reports, participate in discussion, take field trips, listen to resource persons, use audio-visual materials, do research, and work on projects. There should also be activities that reinforce learning for the slow learner, and activities that challenge and extend the knowledge of the fast learner. At the same time, opportunities should be provided for children to investigate incidents or problems that arise and are not part of the planned program.

PROVISION FOR INDIVIDUAL DIFFERENCES

The science program should provide for the individual abilities, needs, and interests of the children. It should offer a wide range of learning activities that will help the individual growth of children in science. The children should be given an opportunity to work in large groups, in small groups, and individually. It will allow slow learners to participate actively with the other children and to learn from them, yet permit them to work individually or in small groups for remedial purposes. It will enable fast learners to share their knowledge and ability with the other children, thus helping them, and yet it should permit the fast learners to extend their own knowledge and to explore further in areas which interest them.

Some schools have made changes in the organizational pattern of the classroom, claiming that one of the advantages of such changes is the greater opportunity to provide for individual differences in children.

One such organizational change is the nongraded classroom. Most schools have self-contained classrooms, where each classroom is under the direction of one teacher for one full year or grade. The nongraded classroom disregards single grade levels. Instead the children are placed in flexible groups on the basis of several related factors. They spend three years, and occasionally two or four years, in one group before moving on to the next group. Consequently, the children have a better opportunity to progress at their own individual rate and optimum speed at a time when maturation and growth in children is notoriously uneven and unpredictable.

Some schools have adopted team teaching, where two or more teachers are assigned to a group of pupils. This arrangement calls for different schedules and different allocations of time and space for teaching and learning. Team teaching lends itself to differences in grouping, thus providing for large-group, small-group, and individual learning activities as needed.

Other schools have departmentalized their science (and other) programs, so that a teacher with a good science background and with expertise in the teaching of science is responsible for the learning of science by all the children in one or more grades. This background and expertise presumably enables the teacher to provide more and better learning activities that will take into consideration the individual differences of the children.

PROVISION FOR NECESSARY MATERIALS

It is useless for a science program to include "doing" learning activities unless the necessary supplies and equipment are made available. Thus an annual budget must be allotted to the elementary school for science

materials so that the science program can function successfully. Moreover, each classroom should have its own science library, and the school library should have an adequate selection of science books. Provision must also be made for easy accessibility to films, filmstrips, and television programs.

HELP AND ENCOURAGEMENT FOR THE TEACHER

Giving the elementary teacher as much help as possible is an important facet of any planned science program. An examination of current elementary science textbooks shows that approximately 33 per cent of the content is in the area of biology, 33 per cent is in the area of physics, 20 per cent is in the area of geology, 8 per cent is in the area of astronomy, and 6 per cent is in the area of chemistry. (Meteorology is incorporated into the area of geology.) Thus to teach science effectively in the elementary school, the teacher should have a certain measure of knowledge and proficiency in these five areas. Unfortunately, this knowledge and proficiency requires a greater science background than most elementary school teachers receive in their pre-service training. It is generally agreed, and is verified by the findings of research, that most elementary school teachers have inadequate science backgrounds. Consequently, many of these teachers are reluctant to teach science.

Therefore, if teachers with an inadequate science background are given units that do not contain the basic science information, the teachers will be reluctant to use the units. This situation is easily understandable because all teachers realize that, unless they are at least moderately qualified to teach any subject, they may eventually be put into the embarrassing position of appearing inept before the children. A teacher does not mind saying "I don't know" occasionally to the children. But, when she has to say "I don't know" repeatedly, she soon stops teaching the particular topic or subject that places her in this awkward position. The teacher prefers to teach subjects in which she feels competent, comfortable, and secure.

If one of the objectives of science is to help the children understand and learn key concepts and conceptual schemes, it is imperative that the teacher be well informed about the science content and process that is being studied. Otherwise the teacher will not be able to guide the children's learning profitably.

Teachers can be given help in several ways. Providing them with science textbooks on both the junior and senior high school level can do much to upgrade their limited science background. A large number of reference books on individual science topics at the elementary school level are now available. The teachers can be provided with excellent professional books, sourcebooks, and curriculum materials on elementary science. In-service education in science content and process, in the form of workshops or courses, can be offered.

Many of the larger school systems are beginning to employ science supervisors or coordinators. These persons, proficient both in science and in working with children, can do much to strengthen the science program and the morale of the teachers. They can plan with the teachers, suggest additional learning activities, frequently do demonstration teaching, locate and order equipment, and conduct local workshops.

Some school systems employ full-time science supervisors or coordinators. They are given either a limited teaching schedule or none at all so that they can spend most of their time working on the program or with those teachers who need help. Other school systems may have a supervisor or coordinator on a part-time basis. Sometimes school systems use a competent junior high school teacher, who is given only a half-time teaching load so that the rest of the time can be devoted to the elementary teachers. Sometimes they use a science-minded elementary school teacher, letting someone else take over her class part of the time while she works with the other teachers in her building. Some school systems have a science educator come periodically to furnish advice and assistance to the teachers. Planned science programs in the elementary school are still comparatively new, and the position of elementary science supervisor or coordinator is even newer. The trend, however, seems to be quite definitely toward the increased use of full-time supervisors or coordinators.

SUFFICIENT TIME

There is definite agreement that science should be a regular part of the daily program, and have adequate time within the program. Both interest and learning are lost if science is scheduled only once or twice a week. Opinions vary, however, as to how much time should be allotted to science, daily or weekly. The general feeling is that more time should be devoted to science in grades 4-6 than in K-3. Some schools require that a definite amount of time be devoted daily to science. One recommended time allotment is 20-30 minutes per day for K-3 and 30-40 minutes per day for grades 4-6. Some schools set aside three days a week for science, with an average of 40-60 minutes per day. Other schools merely stipulate a definite amount of time per week, usually 120-180 minutes, and let the teacher allocate the time as needed throughout the week. Still other schools require that science be taught, but leave the time allotment to the discretion of the individual teacher.

CONTINUOUS EVALUATION

To be effective the science program should be evaluated continually, with everyone involved in the program participating in the evaluation. The

scope of science content must be examined for corrections, additions, or deletions. The sequence must be evaluated to ensure optimum grade placement. Activities should be scrutinized critically to see whether they are achieving maximum learning of content and process. Newer, more productive activities should be substituted as they appear in text, reference, and resource books. Initiating activities may be evaluated for greatest possible motivating and problem-raising potential. Even the evaluation techniques themselves should be examined regularly to see whether learning is taking place in the classroom.

CURRICULUM DESIGN IN SCIENCE*

Fletcher G. Watson

Fletcher G. Watson, reflecting upon the complex problems of curricular design, pleads for specificity and clarity in any statement of objectives. He believes that objectives must be stated operationally for at least four reasons: (1) The several individuals working on a curriculum need to agree on their targets so they can work together effectively. (2) Explicit objectives in terms of pupil behavior must be used to appraise the effectiveness of materials. (3) School administrators and parents should be provided with explicit statements of the purposes of the instruction proposed for their children. (4) Teachers need to know what is expected, or otherwise they may unintentionally distort the intent of the instruction as initially planned. Dr. Watson also discusses five necessary dimensions of planning.

The redesign of science courses and curricula is an important and continuous operation. Yet in many instances, this important task is approached within an overly limited framework that fails to consider many of the dimensions that must be met. Any group, whether local, state, or national, that undertakes curricular reforms must assume responsibility for all aspects of such procedures.

Time in the classroom is precious. Each pupil may experience about 180

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sessions in a year; whatever he takes away at the end of the year depends upon what happens during those brief and fleeting sessions. Perhaps the teacher can "learn through experience" year after year, but the pupil has only one chance. Therefore, much effort is desirable to ensure that even the first time a new curriculum or course is used it accomplishes the purposes for which it was intended.

Reflecting upon the complex problem of curricular changes, the following comments are given to stimulate discussion, to emphasize the range of factors that must be considered, and to plead for great attention for specificity and clarity in the statement of objectives. As an ultimate criterion of a successful plan, it could be sent through the mail to a distant (and competent) teacher who would agree that his instruction from this material paralleled that of the maker to the extent that they could properly use the same examination.

LEARNING BEHAVIOR

Since the several courses of study or the over-all curricula are blueprints or guidebooks to possible teaching, their effectiveness depends upon what they communicate to the teacher. The teacher receives the blueprint, considers it, interprets it, (and perhaps distorts it). Then he performs some operations in the classroom. There, in its starkest simplicity, X "teaches Y" to Z. The term "teaches Y" comprises the actual curriculum to which the pupil, Z, is exposed.

But a persistent problem faces the teacher: what has each pupil learned, and how can the teacher become aware of this learning? As it is impossible to see the brain cells "turn from blue to pink," the learnings are *inferred* from our observations of the changes in pupils' behaviors. Thus, from the start, clear statements of anticipated behaviors (hopefully new and socially significant ones) must be of central concern to all curriculum planners. French (1) and Kearney (2) pointed out the importance of stating teaching objectives in behavioral terms, but unfortunately this approach has usually been neglected.

Fundamentally, the planning of instruction involves the design of a predictive system relating the input of experience through pupil and teacher behavior to the output of changed behavior by the pupil (and possibly also by the teacher). For the essential moment-to-moment and day-to-day modification of classroom efforts, the teacher needs clear and immediate feedback evidence of the pupils' learning. That is, he must have specific expectations of how *these* pupils will react to *this* setting. The difference between the teacher's expectations and his classroom observations of pupils' actions comprises the error-signal which the teacher uses to modify his subsequent behavior during the lesson. Those designing curricula and courses of study assume the responsibility for making clear

their expectations of the resulting pupil behavior—the criteria for evaluating the effectiveness of a particular teaching procedure with particular experiences by particular pupils.

Over the past years greater clarity in objectives has been attained by shifting from such topical headings as: parallel circuits, or the liver, to such form as understanding that: (followed by a complete statement) (3). Yet we naively proceed on the assumption that learning is an all-or-nothing operation; either the pupil “understands” or he does not. All teachers know that understanding grows slowly and is never complete. Help must be given the teacher to estimate the degree to which the pupil understands. To aid in sharpening these objectives, propose that they be stated in terms of “virile verbs” such as: plan, predict, make, compute, read, demonstrate, seek, criticize, argue, hypothesize, test, etc. Probably such pupil actions occur to the teachers as they are planning curricula and lessons, yet rarely do they get stated sharply as the basis for evaluating the proposed instruction. Instead, evaluation often takes the traumatic form of a test made (often hurriedly) after the instruction, rather than planned from the start as an integral and continuous part of the instruction.

The changed behaviors that may result are legion; some are desirable while some are undesirable. Some depend upon what is taught, and some depend upon how it is taught. But not “everything” can be taught, and not all behaviors can be developed simultaneously. Therefore, selection and pacing are necessary. Thus, the curriculum is seen as planned input of experience with chosen procedures intended to produce a developing series of behavioral changes in the particular pupils enrolled in a course.

In the past, teachers have been laboring under disadvantages because syllabuses and textbooks have failed to specify the anticipated pupil behaviors. Busy teachers with their individual backgrounds and images of what was proper have been obliged to infer what was desired, or desirable. Too often the teacher’s behavior was reduced to “talk and chalk,” and the pupils’ to responses on certain examinations which sample only a limited and often minor portion of the pupils’ capabilities. Teachers, professors, parents, and employers expect more than the competencies exhibited on tests. The larger goals must be planned into the instruction and continuously evaluated during the act of teaching by planned and careful observations of the pupils’ behaviors in specific programs.

OBJECTIVES

Objectives must be stated operationally for at least four reasons: (1) The several individuals working on a curriculum need to agree on their targets so that they can work together effectively; (2) During any tryouts of draft materials, explicit objectives in terms of pupil behavior must be used to appraise the effectiveness of the materials. Lacking this, no one knows whether what happened was what was intended to happen; (3) School administrators and parents should be provided with explicit statements of

the purposes of the instruction proposed for their children; (4) Teachers need to know what is expected or otherwise they may unintentionally distort the intent of the instruction as initially planned.

The dimensions of planning are many. At least five, of which each is necessary but not sufficient, can be recognized. These are: (1) The large and small concepts which constitute the structure of the particular subject; (2) The many procedures which give vitality, continuity, and commonality to the efforts of scientists (process goals); (3) The peculiar characteristics of the learner: his age, sex, and the cultural attributes of his community; (4) The intellectual behaviors of classifying, transforming, and formalizing (among others) through which each individual appraises and organizes his experience into significant conceptions; and (5) The appropriate tactics and strategy of teaching through which the teacher evokes in the learner the particular responses desired from the instructional setting.

1. Most groups begin their planning with the conceptual structure of a science: the ideas, explanations, or the theories which constitute the discipline of a science. Presumably a relatively small number of general scientific conclusions would serve as the framework for a long-term curriculum. Small blocks of instruction would be concerned with numerous specific concepts which contribute toward developing in the pupils a growing awareness of the grander concepts. As an example, consider the six major generalizations which Brandwein recently proposed (4).

- a. Under ordinary conditions, matter can be changed but not annihilated or created.
- b. Under ordinary conditions, energy can be changed or exchanged but not annihilated or created.
- c. There is an interchange of materials and energy between living things and their environment.
- d. The organism is a product of its heredity and environment.
- e. The universe, and its component bodies, are constantly changing.
- f. Living things have changed over the years.

While Brandwein spelled out the possibilities of these generalizations, they are used here only to suggest the kind that would give continuity and structure to a long-term curriculum.

2. Practice with the processes by which scientists go about their tasks individually and collectively comprises another type of objective. These are called "process objectives, or themes." Consider the following examples:

- a. Man extends his limited sensory capability by the use of various instruments; the invention of novel instruments has opened up large new fields for scientific investigation.

- b. Various forms of models and analogues, including working replicas, verbal statements, as well as mathematical formulations, are frequently used to simplify and organize experience.
- c. Through journals, meetings, and letters, scientists report and discuss their work with those of similar interests in many countries.
- d. Scientific studies are concerned with describing phenomena in parsimonious terms; technology is concerned with practical applications.
- e. Since scientists are conscious of the limitations of their generalizations and of the many shortcomings which can occur in generalizing from limited experience, they expend considerable effort upon the testing of generalizations to establish the conditions under which they apply and do not apply, especially the latter.

While lists of such objectives have been published (5), almost surely any curricular group would wish to make its own phrasing and condensation of the important aspects of scientific work which are inherent in the particulars being studied.

3. Inasmuch as the total effort of the school is to bring about changed behavior in the child, the design of curricula without careful consideration of the pupils may be unrealistic. Teachers and educators must be concerned with the learner as a social individual of a given age having a unique and limited background of relevant experiences. The sex of the learner seems to be important, if not in cognitive abilities, at least in the motivation to interpret and structure the phenomena observed. In addition, each learner exists in a subculture of his family with its peculiarities and in a larger culture of the community with its unique attributes depending upon the geographical locations, the particular group of individuals that have settled there, their financial status, their religious beliefs, and their interest in academic learning. Here groups planning curricula (or textbooks) for use nationwide may encounter difficulties.

4. Another attribute of the individual learner, as described through the investigation of Piaget and Inhelder (6) (7), Bruner, *et al.*, (9), Vygotsky (10), and many others deals with his ability to organize his experience in various ways. While it is not yet clear to what extent these abilities are "age-bound," at least they appear to occur in a sequence. In discussing such developments, the psychologists refer to the child's ability to classify objects and experiences into various category systems, to perform various transformations by rearranging the entities presented to him, to utilize symbols for objects (initially words and later more abstract mathematical symbols), and ultimately to organize his experience formally in terms of "might be's" and then check the natural or contrived phenomena to see what actually does occur. Apparently most of the operations are acquired gradually and naturally by the typical child by the age of 12 to perhaps 14. Therefore their consideration in the planning of science instruction for

young children would be particularly significant. There is no guarantee however that older children or adults have actually become competent in each of the operations and the strategy decisions that are necessary in the selection and application of appropriate operations.

5. This fifth objective is concerned with clarifying the act of teaching. In the classroom, the teacher's image of what is important, and his manipulation of what educators call the "classroom climate" has a significant influence upon the ultimate yield of the instructional materials. The way in which the instruction is approached and the clarity to the teacher of what is important to gain through the lesson reminds us that teachers can have widely differing initial views of what might and could be done with the materials. As self-protection against misinterpretation each curricular group should communicate to the teacher point by point the major intent of the instruction with suggestions for classroom procedure expected to evoke the desired pupil behavior quickly and efficiently. Thus, the method of teaching—the teacher's classroom behavior—is deducible from the particular objectives of the lesson (aspects 1 and 2 above), from the environmental factors (aspect 3), and from the competencies of the pupils (aspect 4).

CONCLUSION

Any effective approach to curriculum planning must include consideration of at least five distinct aspects of which each is necessary, but not sufficient. The entire process is clarified and made operational by a central concern for the changes sought in pupil behavior, for these guide the teacher in the classroom and provide continuous criteria for appraising the effectiveness of the instruction.

References

1. Will French, *et al. Behavioral Goals of General Education in High School*. Russell Sage Foundation, New York. 1957.
2. Nolan Charles Kearney. *Elementary School Objectives*. Russell Sage Foundation, New York. 1953.
3. Paul Brandwein, F. G. Watson, and Paul Blackwood. *Teaching High School Science: A Book of Methods*. Harcourt, Brace and World Company, Inc., New York. 1958.
4. Joseph Schwab and Paul Brandwein. *The Teaching of Science*. Harvard University Press, Cambridge, Massachusetts. 1962.
5. Glen Heathers. "A Process-Centered Elementary Science Sequence." *Science Education*, 45:201. April 1961.
6. Bärbel Inhelder and Jean Piaget. *The Growth of Thinking from Childhood to Adolescence*. Basic Books, Inc., New York. 1958.
7. Jean Piaget. *Logic and Psychology*. Basic Books, Inc., New York. 1957.

8. William Kessen and Clementina Kuhlman. *Thought in the Young Child*. Monograph 83. Society for Research in Child Development, Inc., Purdue University, Lafayette, Indiana. 1962.
9. Jerome Bruner, Jacqueline J. Goodnow, and George A. Austin. *A Study of Thinking*. John Wiley and Sons, Inc., New York. 1956.
10. Lev Semenovich Vygotsky. *Thought and Language*. Massachusetts Institute of Technology Press, Cambridge, Massachusetts. 1962.

THE ELEMENTARY SCIENCE PROGRAM*

National Society for the Study of Education

The following is an excerpt from Chapter 7, "Developing Science Programs in the Elementary School," of the Fifty-ninth NSSE Yearbook, Part I, Rethinking Science Education. Members of the committee who wrote this chapter include Glenn O. Blough, Paul E. Blackwood, Katherine E. Hill, and Julius Schwartz. The committee describes how successful programs have their origins in a variety of sources: (a) the child, (b) the environment, (c) the sciences, and (d) the total school program. All these sources must be considered when planning the program. Also, the properly organized program should have structure and sequence.

HOW THE SELECTION OF SUBJECT MATTER IS MADE

Experience in the teaching of science in the elementary school has demonstrated that the most successful programs have their origin in a variety of sources: (a) the *child*, with his emotional, intellectual, and physical needs; (b) the *environment*, both natural and man-made, in which the child lives; (c) the *sciences*, especially biology, chemistry, physics, and astronomy; and (d) the *total school program*, as it relates to the needs of *society* for informed citizens, capable of participating in social living.

Curriculum-planning has sometimes drawn heavily upon one of these sources without due regard to the others. Thus, in some localities, science has been made an adjunct to social studies, whereas in others the science program has leaned heavily on selected features of the local environment. In some instances, the science program of the elementary school has been

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designed as a "simplification" of junior and senior high school science. This "watered-down" approach, while generally rejected at this time, crops up sporadically in some "crash" programs which attempt to "scale down" upper-school apparatus, experiments, and ideas to "fit" young people.

Science programs drawn chiefly from one source are sometimes helpful in demonstrating the limitations of such programs. Today, however, there seems to be widespread agreement that the most vital programs are those based on the needs of the child in his environment, programs which are in harmony with the total school program and mindful of the needs of society and which utilize the materials, concepts, and methods unique to science. The process of curriculum development involves the exploration of *all* these sources to find in them the content and the methods for the science program. Curriculum projects as designed are generally prepared by teams of classroom teachers, supervisors, curriculum specialists, and personnel from teacher-training institutions and community organizations.

Owing to recent developments such as those noted, elementary school science is now for the first time achieving full and independent status; it is no longer to be found on the periphery of other subjects in the elementary-school program; nor is it regarded as a downward extension of upper-grade science. Elementary science is now beginning to develop its own structure. It is discovering its own setting and its own problems as it develops programs drawn from each of the four enumerated sources. Let us explore individually these sources.

THE CHILD. The curriculum in science is based on the nature and needs of children: on their delight in sensory experiences, their sense of humor, their curiosity, their concerns, their ability to generalize and to apply principles, and their urge to create. It recognizes that children are different—varying in rate of growth, in manual dexterity, in kinds of experience they have had, in the depths of their interests, and in their capacity for learning.

Children respond with enthusiasm and understanding when they are provided with wire, batteries, switches, and electrical devices like bells, lights, and toy motors and are encouraged to experiment with these materials.

Children get deep satisfaction from firsthand experiences with the forces of nature. They sense the spirit of science when their curiosity is rewarded with discovery.

As teachers, we get clues to science content when we listen intently to children's questions. We get other clues from our observations of toys they play with, the way they spend their afternoons, the television programs they watch, the books they select for reading, the sports and hobbies they engage in, the responsibilities they accept at home, and the pets they take care of.

The science program should encourage creativity and originality in the

activities of children. These traits may be fostered by providing materials and situations which permit children to investigate problems and practices which are new to them, and which encourage creative expression reflecting their individual talents and capacities.

THE ENVIRONMENT. As has been indicated earlier, one of the important values of science in the elementary school is that it contributes to the child's understanding of his immediate environment at a time when he is most curious about it and most ready to explore it. The typical questions asked by children illustrate this breadth of curiosity.

It follows that each school should build into its curriculum the peculiar features of its own environment. The nearby river, the "empty" lot, the park, the brook, the swamp, the tree on the street, the vegetable market, the bakery, the flower shop, the large gas tanks, the school bus, all these are resources that can be utilized.

THE SCIENCES. We have observed how elementary science stems from the needs of children and how it flourishes when it is rooted in their environment. However, the uniqueness of elementary science is derived from the content of organized knowledge and the methods of discovery inherent in the formal sciences.

In designing the elementary-science curriculum we look to the basic sciences for both answers and questions. We look to biology, physics, chemistry, geology, and astronomy for answers to questions arising out of the total life of the child; we seek answers that furnish facts, concepts, principles, techniques and materials, approaches and methods. We look to these sciences also for key questions which will lead children into the structure of organized science. Science gives information; it furnishes concepts and principles; it suggests techniques and materials; and it provides approaches to problems and methods of thinking. Science asks questions. While rejecting the idea that elementary science is a watered-down version of the science of higher levels, we should not disregard the opportunities which present themselves for using guidelines which may help lead young people into the formal sciences. When, for example, we encourage children to discover that shape has something to do with buoyancy, we are starting them on the way to an understanding of the principle of flotation. When children are led to uncover, layer by layer, the disintegrating leaves of a forest floor, they are on the road to understanding the cycles which make life on earth possible. When they experiment to find out how to make their electromagnets more powerful, they are acquiring concepts which will be useful when they study electromagnets in advanced courses.

We find the clues to problems like these by looking for them in the structure and history of the various sciences, in their methods of discovery, and in the important concepts and principles which run through them. Incidentally, the study of the history of science is

especially fruitful in suggesting many experiments which represent great triumphs of scientists, yet which children of today can perform and understand.

The search for these guidelines to the sciences is facilitated when curriculum teams include individuals who have had training in the various sciences. For example, personnel from high school and college should be included; perhaps doctors, engineers, geologists, and chemists of the community may help; so, too, may representatives of scientific, technical, and business institutions. From the use of teams of such diversified membership a broader understanding of the problems at all levels may result.

In the last decade there has been a strengthening of the sequence for science from Kindergarten through Grade XII. Articulation between the various levels is being advanced as the elementary schools look more intently at the science content of the upper grades and expect to include these observations in their planning. Articulation is also strengthened as the philosophy of the junior and senior high school embraces more of the educational values which the elementary schools have found so invigorating in the last three or four decades.

THE TOTAL SCHOOL PROGRAM. A basic premise underlying the science program is that it should be in harmony with the total program of education. This implies that elementary science is an integral part of the fabric which includes social studies, language arts, music, mathematics, art, and health education. Science brings new strength to the elementary schools. Its methods, its approach to problem-solving, and its informational content enrich the whole program and give it new scope and depth.

Social studies, which in Kindergarten through Grade VI includes geography, history, and civics, is, of all subjects, the one most closely allied to elementary-school science. Its concern with problems of living and working together in the home, school, neighborhood, community, or country makes social studies a good background for many science activities. Communication, transportation, food, clothing, shelter, water supply, are topics which are shared by social studies and science.

"If in the social studies, for example, a class is studying the buildings and building construction in their neighborhood, questions with science implications will undoubtedly arise. The children will want to know about some of the materials used—wood, rock, iron, glass, bricks, sand, cement—their origin, their preparation for use, their qualities. . . . They may be interested in some of the machines—wheels, levers, gears—that move things. They may explore the ways in which buildings are protected from the weather. As they watch men at work connecting utilities to the building, they learn about water, sewage, electricity, and telephones."¹

¹ *Science, Grades K-6*. Curriculum Bulletin #3, 1958-59 Series. New York City Board of Education.

But supplying information is only one of the contributions that science makes. Science vitalizes units by encouraging children to raise questions and to find ways of answering them. When children are permitted to experiment with materials and to find out, for example, why steel bridges and iron fences are painted, how concrete is made and used, why a lever makes some kinds of work easier, why water rises in the pipes of a tall building, or why electric wires are insulated, they are doing more than talking about science; they are living it.

Science is allied to mathematics because of its emphasis on measurement, accuracy, and numerical relationships and because it suggests many uses for mathematics in real life situations. Using instruments such as the thermometer and the rain gauge and making calculations required in planning models for a planetarium are illustrations of the use of mathematics in science.

Science makes use of language arts and art skills. Reading, writing, listening, speaking, painting, and sketching are essential tools in elementary science. Here again, the necessary skills are developed by the science program as the child needs them.

The foregoing observations do not mean that science serves only to enrich other areas. Science is the center for many units of planned, co-ordinated experiences, organized around central scientific themes and problems. These science-centered units draw on skills and knowledge from the other curriculum areas as need indicates; but their over-all focus is on science.

ORGANIZING THE PROGRAM

THE STRUCTURE. The National Society's Forty-sixth Yearbook pointed the way to the organization of the elementary-science program, stressing the importance of acquainting pupils with the broader areas of the physical and biological environment by introducing such subjects as the universe, the conditions necessary to life, living things, physical and chemical phenomena, and man's attempts to control his environment.²

During the last decade, elementary-school science has succeeded in developing many vital experiences for children within these broad areas and in suggesting sequences of unifying concepts from the kindergarten through the sixth grade. A wealth of content in science is emerging as a result of the efforts of classroom teachers, science specialists, curriculum workers, college teachers, and writers of children's books. Although science programs vary markedly from place to place, content areas such as the following appear in many curriculums: living things, earth in space,

² "Organization of the Curriculum in Science," *Science Education in American Schools*, pp. 75-76. Forty-sixth Yearbook of the National Society for the Study of Education, Part I. Chicago: Distributed by the University of Chicago Press, 1947.

communication, transportation, resources of the earth, magnetism and electricity, weather, machines, changes in the earth, and health.

These areas—or similar ones—are broad enough to serve as centers for organizing many experiences and activities to meet the needs and interests of children and, at the same time, are rich enough in science content to provide for sequential mastery of science concepts and principles.

Different schools and school systems allocate content to individual grades in different ways, depending on various factors, such as basic philosophy or the nature of the experience of their teachers. Some have divided the content to provide specific teaching materials for each of the grades, Kindergarten through Grade VI. Other schools or school systems have organized the content for groups consisting of two or more grades, as for example, Kindergarten-II, III-IV, and V-VI. This broader grouping permits great flexibility in developing science instruction while providing for a measure of continuity.

ADVANTAGES OF STRUCTURED PROGRAM. Those who advocate an unstructured program in elementary science argue that teachers should be guided solely by the interests of the children. They regard a course of study as stultifying and unnecessary. There is no question but that some excellent teaching has been done without a structured program in a number of small school systems, particularly in those in which science consultants were available or in which the teachers have had an unusual background in science. However, the claims for a structured program are more compelling.

1. A structured program provides a framework of science principles which can help teachers unify their own experiences and give them confidence in meeting difficult classroom situations that arise. The answer suggested a decade ago to children's questions—"I don't know, but let's find out together"—is not sufficient for all of today's needs.
2. A structured program does not have to be a rigid one. Within the broad content areas, there are many choices which permit the teacher to adapt the program to the needs of the class. Both the unit approach and the provision of a variety of materials and situations which foster children's creativity and originality are possible within a structured program.
3. The freshness engendered by the use of unanticipated incidents is not lost in a structured program. Indeed, the incident becomes more significant because the teacher sees it as part of the whole and thus may be able to convey its importance to the pupil. A structured program helps the teacher anticipate, identify, and incorporate into the program the many incidents which arise during the school year.
4. While it is true that children come to school with many interests, it is also true that interest can be aroused and cultivated by what takes place in school.

But supplying information is only one of the contributions that science makes. Science vitalizes units by encouraging children to raise questions and to find ways of answering them. When children are permitted to experiment with materials and to find out, for example, why steel bridges and iron fences are painted, how concrete is made and used, why a lever makes some kinds of work easier, why water rises in the pipes of a tall building, or why electric wires are insulated, they are doing more than talking about science; they are living it.

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4. While it is true that children come to school with many interests, it is also true that interest can be aroused and cultivated by what takes place in school.

5. A structured program makes it easier for children to acquire the science concepts essential for their understanding of the complex world they live in.
6. A structured program is a democratic one: many can share in building it and in changing it. It provides a common framework for testing and evaluation by the children as well as by the teachers.

THE SEQUENCE. Elementary science can serve the general purposes of elementary education, as well as its own unique purposes, if its content provides for children's growth in their understanding of science concepts and principles. Studies of children's development provide clues to the order of complexity of science concepts. Some of the following generalizations have been found helpful in guiding the organization of sequence:

1. The child's view of the world begins with the here and now and extends to the far away and long ago.
2. The child grows in ability to reason, to generalize, to apply principles, to see cause-and-effect relationships.
3. As the child develops physically he is able to participate in activities requiring greater strength and dexterity.
4. The child's increasing capacity for comprehending such dimensions as time, distance, size, speed, direction, or weight may influence sequence.
5. Strong motivation provided by current interests and the special character of the local environment may sometimes outweigh other considerations in the determination of sequence.
6. Sequence will be influenced by the desirability of taking into account the science to come in the upper grades.

Sequence is something that must be tested and judged in the setting of the entire program. Continuous experimentation and careful observation are fundamental to growth in knowledge about what is most appropriate at a specific level.

THE TEACHING OF ELEMENTARY SCIENCE

INTRODUCTION

Planning is essential for successful teaching and learning in the classroom. This may not be readily apparent when one is observing an experienced and skillful teacher at work, because so often the science lesson seems to have developed quite extemporaneously. However, as the lesson progresses, it becomes quite evident that learning is taking place in a logical, well-ordered manner. Problems are raised. The teacher and children together discuss and decide how to solve these problems. Appropriate learning activities are selected and performed. The supplies and equipment needed for these activities appear or are available at just the right time and in just the right place. The reading materials necessary for finding information or for checking conclusions are either present or easily accessible. All this happens because of careful planning and preparation. This makes it possible for the teacher to guide and direct the children's learning of science into profitable channels.

When helping children to learn science, the teacher should always keep in mind that there is no one best method of teaching science. No single method is superior to any other, and one method should not be used constantly in preference to others. A variety of methods is desirable because some methods lend themselves better to a learning situation than others.

Science teaching and learning are always more effective when the learning begins with a problem that arouses the curiosity and interest of the children. The problem may come from a number of different sources. It may come from the teacher, the curriculum guide, the textbook, a current event, or even the children themselves. Planning ways and means of solving this problem will help determine the appropriate method to be used and will also help decide the selection of suitable learning activities.

Provision should be made for the use of a wide variety of learning activities. The children should be given the opportunity to do experiments, to read, to give reports, to participate in discussions, to take field trips, to consult resource persons, to use audio-visual aids, to do

research, and to work on projects. All these activities are the means whereby the children are given the opportunity to perform the key operations of the scientist, and in the process learn science concepts.

Provision must also be made for individual differences. For the slow learner there should be additional activities that will either ensure or reinforce his learning. For the fast learner there should be activities that will challenge his intellectual ability and extend his knowledge. With increasing attention being focused today on the problem of teaching the culturally deprived child, specially designed science learning activities may be both necessary and desirable.

When teaching elementary science, care should be taken that the planning does not become rigid. Planning is necessary, but it should be flexible enough so that as new or unexpected problems arise, they can be easily incorporated into the lesson. In this way the children's investigation can digress at any point, if necessary, without disorganizing the general pattern of learning.

As innovations in education appear, they are quickly adapted wherever possible for use in the teaching of elementary science. Three widely publicized teaching innovations in recent years are educational television, team teaching, and programmed instruction. Of these, television and team teaching are already being widely used to teach elementary science. Although programmed instruction has been introduced with some success in the secondary school, adaptations for its use in the elementary school have been very limited to date.

TEACHING SCIENCE IN THE ELEMENTARY SCHOOL*

National Society for the Study of Education

Certain principles are observed wherever there is good science teaching. These principles are in accord with what we know about children and learning. This article discusses the principles involved in the teaching process, the teaching-learning situation, the characteristics of good science-learning activities, and adequate planning for science teaching. This discussion is an excerpt from Chapter 8, "Teaching and Evaluating Science in the Elementary School," of the Fifty-ninth Yearbook of the National Society for the Study of Education, Part I, Rethinking Science Education. Members of the committee who wrote this chapter include Glenn O. Blough, Katherine E. Hill, Willard J. Jacobson, and Albert Piltz.

Obviously there is no *one* best method for teaching science in the elementary school any more than there is *one* best way to teach any other subject. We shall, however, attempt in this chapter to set forth some principles that, if observed, will raise the level of science instruction. They are practiced wherever there is good science-teaching. They are in accord with what we know about children and learning.

THE TEACHING PROCESS

Problem-Solving

Greater effectiveness in science-teaching is almost sure to result if the learning begins with a perplexing problem—one for which the learner is motivated to seek a solution, either because he has generated his own perplexity or because his teacher has stimulated him to wonder. The problem, then, becomes the motivating factor, and curriculum activities are performed only to solve the problem. The purpose gives focus to the method. It makes selection of the activities clearer; it makes evaluation easier.

Problems to be solved may come from a variety of sources. They may be presented by the pupils; they may be suggested by a current happening;

* REPRINTED FROM *Rethinking Science Education*, 59th Yearbook of the National Society for the Study of Education, Part I (Chicago: University of Chicago Press, 1960), pp. 136-144, by permission of the publisher.

they may come from the teacher, from the textbook, or from a prescribed course of study. Whatever the source, learning will be more effective if pupils become genuinely interested. As has been indicated elsewhere in this yearbook, these problems should constitute a developmental program as the pupils progress through the school.

The Activities

Faced with a problem, the solution of which appears important, pupils are motivated to respond to the question, "How shall we find the answer?" And, if pupils are really to grow in ability to solve problems, they must be encouraged to experiment, observe, read, discuss, look at pictures, inquire, and make use of all available resources for learning. Such activities as these are now performed in order to solve a problem.

Pupils may begin to search for experiments that will shed light on the problems. They may originate experiments for the same purpose. Each experiment is performed so that data may be gathered to apply toward the solution of the problem. Pupils will soon see that it is not possible to learn everything from experimenting. Relying entirely upon experimentation would necessitate jumping to conclusions. They must consult authorities. They must check their findings against what others have discovered. This constitutes the real reason for using the text and supplementary materials.

When it becomes necessary for pupils to study objects or processes not present in their environment, they may use slides, motion pictures, and other visual aids that will help verify or disprove their findings. The method of science constantly cautions the learner to hold conclusions tentative, collect more data, and verify the findings. The method of teaching then becomes a scientific method, simulating on a small scale the method used by scientists.

Many avenues of learning are necessary if the method of instruction is to lead pupils toward the goals of instruction. Science teaching cannot be a reading course and achieve the objectives assigned to it as part of the total curriculum. Neither can it be confused with useless construction of models and painting of murals. Each activity must have focus: the attainment of the objectives.

The Sequence of Learning

Effective science-teaching must be actively concerned with helping pupils develop a logical sequence of ideas as they proceed through the elementary school. The teaching method must make it possible for pupils to build on their previously acquired knowledge, to put together their learning experiences, and to make increasingly complex generalizations.

The method of instruction should be so designed that pupils are

challenged at each new level of their program. As their ability to see relationships increases, so should the expectation of instruction. Unless pupils are challenged to extend themselves as they proceed, it is unlikely that they will achieve the objectives of the science programs.

In the elementary school we need continually to remind ourselves that good methods of instruction in science are similar to good methods of instruction in other areas of the curriculum.

THE TEACHING-LEARNING SITUATION

The Teacher

Any discussion of a good classroom teaching-learning situation may logically begin with an appraisal of the teacher and of his role. There is scarcely anything wrong with the science education in our schools today that some skillful science-teaching cannot cure. The improvement begins with the assignment of a teacher who has a good science background, has a knowledge of the objectives for teaching science, is interested in teaching, knows how children learn, and *wants* to be a good teacher. The teacher, then, is the key to the learning situation. His enthusiasm carries to the learner. His interests often become theirs. His concern for them is reflected in his success as a teacher.

The good teacher is a guide; but he is more than that. Because of his experience and understanding he not only guides but also directs the learning into profitable channels. He keeps learning from being a narrow experience by broadening the interests of the learner and by opening up new avenues of learning.

CHARACTERISTICS OF GOOD SCIENCE-LEARNING ACTIVITY

The impact of the activity movement in education is now legend. The movement is described in considerable detail in an earlier yearbook.¹ Science activity begins at birth when the child first interacts with his physical environment. In his early development his behavior is that of orientation to his surroundings. His inquisitiveness leads him to test his world in a variety of ways.

The elements which comprise a good science-learning activity are not unlike the elements of a good learning activity in other areas. However, there are some aspects of a science activity which are peculiar to science. Just as science, as a tool of learning, has unique contribution to make to

¹ *The Activity Movement*. Thirty-third Yearbook of the National Society for the Study of Education, Part II. Chicago: Distributed by University of Chicago Press, 1934

the educative process, so do science activities make a contribution toward helping children gain in power and in maturity. As has been indicated, problem-solving is essential to effective learning in science; the activity is the vehicle which provides the means for the solution to the problem.

Variety of Activities

In a learning situation, the child carries on activities which help him internalize experience and gain basic understandings commensurate with his needs, abilities, and interests. Certain situations may require different types of activity. Some activities are more effective than others for individuals of different needs and interests. A wide variety of activities should be planned in order to adequately take into account the differences among individuals. Since interest and need are inextricably tied up with children's day-to-day experiences, it is important that activities have both meaning and significance to them if they are to achieve the goals that are sought through problems and developmental tasks.

Variety in the plan of organization of activities is also desirable. In some instances children may, with profit, work together in a certain general area but, within that area, may also pursue their individual interest. For example, if the main area of concern is the International Geophysical Year, interests in rocketry, satellites, orbits, oceans, and Antarctica would naturally arise, and appropriate activities would follow accordingly. Some youngsters might engage in an activity in a related area such as "weather at the South Pole" and remain within the broad organizational plan. Activities may, of course, be of varying length and importance.

Activities and Direct Experience

Whenever possible, children should be given opportunity to gain knowledge of the world about them through direct experience. When children engage in activity in which they gain firsthand knowledge for a purpose, clear understanding and intelligent interpretation of the environment are likely. When activities are related to the life experience of boys and girls, it is more likely that the learning will have greater application to daily living.

ADEQUATE PLANNING FOR SCIENCE-TEACHING

As has been pointed out, the objectives in science can be achieved in many different settings. The structural organization of science education, science as a separate subject or combined with other areas of learning, is significant but not nearly as important as what the teacher and his pupils do daily in the classroom.

Teacher-Pupil Planning

Teacher-pupil planning cannot be structured in advance. The planning and selection of activities should take into account the composition of the group, the competence of the teacher, and the nature of the learning that is in progress. Encouraging pupil participation in decision-making, planning, and evaluation will make the activity more purposeful and the attainment of desired goals more probable. The teacher guides and directs the pupils in the joint planning session.

The extent to which science is taught in the classroom is related in great measure to the degree to which science experience is valued by the teachers and the pupils. The amount taught tends to be large when the significance of science in our culture and its role in education are generally understood.

SOME WAYS OF HELPING CHILDREN TO LEARN SCIENCE*

Beatrice Hurley

Beatrice Hurley discusses some of the kinds of activities which can serve as channels through which children may learn science. This discussion includes such activities as direct observation, field trips, reading, experimenting, and using audio-visual aids. It is intended as a guide for those who seek ways of helping each child learn how to go on learning science for the rest of his life. This article is a portion of a larger article, "What is Science?" which appears in an Association for Childhood Education International service bulletin entitled Science for the Eights-to-Twelves.

Children learn science in a wide variety of ways. Obviously, there is no one blueprint which should be followed by all teachers. The activities selected for and by children should take several factors into account. Greater effectiveness in the teaching-learning process is almost always

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achieved when there is a challenging problem to be solved—one that children feel is worth solving. At times, the problem to be solved comes from a child's proposal; at others, the selection of the problem is the teacher's. And at still other times children and teacher jointly select it. Who makes the selection matters little, if all involved accept the problem as one worthy of solution.

When the solution of a problem is accepted as genuinely important enough to work on, planning must be done and accurate information gathered from many sources. There must be a period of exploration, time for proposals as to how and when the work shall get done and by whom. Shall the entire group be involved in each step, or shall small groups or individuals take responsibility for portions of the work and report their findings to the large group? Well-guided discussions are essential throughout the entire planning and working times. For example, let us suppose that a group of children are finding answers to the question, "What do plants need in order to grow?" This general topic might well be broken up into smaller segments:

What does soil have to do with plants' growing?

What does water have to do with plants' growing?

What does temperature have to do with plant growth?

What does light have to do with the growth of plants?

Children working in small groups or individually could work effectively upon one or another of these questions. One group might suggest experiments which would yield evidence concerning the needs of plants for growth. Another might suggest going to books to find out. Another might suggest a trip to a greenhouse, a farm, a botanical garden to talk to persons involved in successfully growing many kinds of plants.

Children should carry on activities within the large problem area which they are able to tackle with a reasonable expectation of success. Provision for individual differences in interest and maturity should be carefully assessed as decisions of work assignments are made.

It is desirable to use a variety of procedures for finding out. Not all individuals learn equally well, nor do they take the same things from any one experience.

DIRECT OBSERVATION

Whenever possible, and within the bounds of safety, children should be given opportunity to learn about their world through direct observation of it. What a learner learns through seeing, feeling, smelling, tasting and hearing gives him much firsthand knowledge of the nature of things in the local environment. With the use of certain instruments such as a telescope, observations of more distant phenomena can be made.

Young children learn much of what they know through keen use of their senses. Older children should be encouraged to continue to learn in this manner. Skill in observation is perhaps one of the most useful tools a person can acquire. Teachers can enrich the lives of boys and girls by helping them learn how to see and interpret their environment. Children who know where the first crocuses are to be found, when the spring migration of warblers takes place, what stream is best to fish to catch the biggest trout, which kinds of clouds bring clear weather are usually children who have learned to be keen observers of what goes on around them.

Learning is made more vivid and pleasurable through numerous direct observational experiences. The goal worth striving for is growth in accuracy of one's observations and in reporting them to others. The ability to observe accurately is a part of all other activities in science. Without it, experiments are of no value. Excursions benefit children more when blinders have been removed from eyes and children are helped to see what spore cases look like on the underside of fern leaves; how a robin's flight habits differ from those of a hawk; what the buds on a tree look like in midwinter; how a mullein leaf differs from a plantain leaf in the way it feels in your hand.

TAKING FIELD TRIPS

Some of the most valuable learning situations occur outside the classroom. The distance covered from school to the place to be visited is not the measuring stick for the value of an excursion. Every local environment holds numerous possibilities for fruitful observational experiences. There are inexhaustible resources for teaching science in any community, even in one that at first may appear to hold few possibilities for direct learning through trips.

Within the school building itself investigations could be made that might include:

- How our school is heated.
- How electricity comes to our building.
- Where the fuse box is.
- How the intercommunication system works.
- How food is prepared in the cafeteria.
- How garbage is disposed of.

A study of the schoolyard has much of value for learners. Suggested investigations are:

- Places where soil is being eroded or where grass grows best.
- Do animals live on the schoolground? If so, what do these animals find to eat?

Where do they make their homes?

What kinds of trees and other plants are there that can be studied throughout the four seasons?

What machines are used in play equipment on the playground?

Exploration of these things helps bring science into the lives of children.

Moving away from the school and schoolground, there is the community to explore—persons, places and things. Trips to fields, farms, bogs, a vacant lot, a zoo, a park, a stream, an excavation or an abandoned quarry can acquaint children with a great variety of living and nonliving things and give them knowledge of how these living and nonliving things are interrelated. Return visits to places help children realize the changes that occur as seasons pass. Likewise, trips to processing and manufacturing plants, a telephone exchange, newspaper printing plant, TV station or water purification plant can reveal much of man's use of technological advances.

Almost any community has resource persons who can offer enrichment to the school curriculum. A teacher's source file of such persons will help children to benefit from the talents of special people in the community. There may be an amateur astronomer, a naturalist, a conservationist, a geologist, a photographer with color film and slides, a tropical fish keeper, a physician or a world traveler, who would be glad to share knowledge and experiences with boys and girls.

Trips into the community should be carefully planned ahead of time. Children should know the object of taking the trip, what they wish to find out while there. They should keep records on the spot, make sketches or take pictures if these activities are appropriate. One of the goals the teacher should hold in mind is to make more careful observers of children. Also, children should learn to check their observations of natural phenomena with reliable sources, a necessary operation which requires the use of books.

READING

Through reading children learn about the ideas of others. Books are useful tools for learning science. It is important to recognize that factual textbooks and trade books should be used to add information to a topic under consideration and should be consulted when unanswered questions are hanging fire. Under these conditions, children go directly to that part of the book dealing with their specific concerns. The learner may have any of several reasons to consult a book. He may wish to check his own conclusions; to get added information; to learn how to do an experiment; or to answer a question.

Using factual books in this manner helps children learn to use books effectively and efficiently. Skill in using encyclopedias is not quickly

learned, but teachers who guide children in using their science textbooks and single-volume factual books as research tools build basic skills for using encyclopedias and other complex reference books.

Many teachers have in the classroom library factual books and other reading matter relating to science topics, chosen with concern for the varying reading abilities of a group of children. Assignments of topics can then be made for the individual child, using books neither too hard nor too easy. Developing skill in reading and learning science can go hand in hand if the teacher guides children well in their selection of books and other reading matter.

Thoughtful, deliberate reading of science material often sparks discussions that further enhance children's understanding of a given topic and of new topics as well. Varying points of view of authorities may cause children to question authoritative sources. Lack of agreement may also help children sense the tentative nature of much that is now known and thought to be fact. This, in itself, is a valuable experience. A healthy skepticism is a wholesome attribute.

From the foregoing, it must be evident that books and reading have an important role to play in the science program. It must also be clear that "Open the book to page 34 and read to page 39" is an undesirable kind of assignment.

Sometimes an interest catches fire in the classroom that leads children to search for new information not readily found in textbooks.

Such a search engaged the energies of a group of sixth-graders. As an offshoot of a study centering around the concept that "we are caretakers of the environment," these children learned that some animals once numerous are now extinct and that others are on the way to becoming so.

Committees set to work to find out which animals had already died out and why; which ones were threatened with extinction, and what was happening to correct the situation. This search led children to magazines, bulletins, daily papers, movies, TV programs and books for information about whooping cranes, the condor of California, the bald eagle now scarce in this country, and other scarce animals throughout the world. The children were stunned to learn that giraffes are still being slaughtered, not for food, but for their tails which are marketed as flyswatters, and that the rhinoceros are killed for their horns which are ground into a powder that is an aphrodisiac.

The New York Times of December 22, 1963, carried a story of the killing of 351 rare, gray seal calves on an island in the North Sea by marksmen from the Ministry of Agriculture, Fisheries, and Food. Fishermen had complained that the calves were damaging their nets and eating their fish. The children were puzzled at the wanton destruction of seal calves by a body of men engaged in the conservation of wildlife. Was this not a shortsighted act on the part of these men? "Aren't there wiser ways to keep nature in balance?," they asked. Many more questions were asked.

But the children's faith in human nature was somewhat restored as they learned of the exciting wildlife survival centers being set up in many zoological parks for breeding stock of endangered species. Children's letters to persons planning these centers brought replies with many details concerning which animals were to be protected.

If it is true that concepts govern actions, this vital science enterprise may well have conditioned the behavior of these sixth-graders in matters pertaining to the responsibility of each as a "caretaker of his environment."

Among the concepts that the teacher sought to advance in this experience were the following:

Countless species of plants and animals that once lived on Earth are nowhere to be found today.

Once a species has died out, it is never likely to develop on Earth again. Thoughtless acts may cause great damage.

Sometimes men have helped to cause the extinction of some living things.

Sometimes men have helped to save species of living things from extinction.

Boys and girls not only need to learn about the living things in their environment, but they also need to learn the importance of their actions in bringing about change.

Part of this understanding about the importance of individual acts can be gained by studying some of the changes which have occurred in the past.

Each individual is responsible to some degree for the care of his environment.

Concepts of such magnitude clearly illustrated that this teacher was not concerned with pouring in a mass of small facts. To be sure, a great number of facts were uncovered and utilized, but it was not the memorizing of small content that guided the teacher as she worked with the boys and girls. Her goals were changes in behavior, deepening of understanding, appreciation of the vital role of each individual in enjoying and protecting the environment. The teaching of science that aims at changes in behavior is quite different from that which is set out to be learned, such as covering the book and passing the test.

EXPERIMENTING

An experiment is an activity intended to supply information in solving, or helping to solve, a problem. It is a means to an end rather than an end in itself. Experimentation is conducted primarily for learning something that the experimenter does not already know.

Let us suppose a fourth-grade child asks, "Where is the attraction of a magnet strongest?" He asks because he doesn't know the answer. This is the moment for the teacher to suggest that he go to the storage cupboard, get a magnet and experiment to find the answer he seeks.

Equipment for most experiments done in elementary school should be

simple. A paper bag can be used as successfully as a bicycle pump and tire to show that compressed air can do work. Occasionally, the use of simple materials stimulates children to improvise equipment from materials at hand; often such improvisation is ingenious and quite creative.

In guiding experiments done by children, the teacher needs to bear in mind that the factor of *control* is very important; that is, all conditions must be the same except for the experimental one, called the *variable*.

For example, a child might set about to find out "what would happen to green plants if there were no more sunlight." One way to find out is to plan an experiment. Since the answer is not known, the situation is truly experimental.

The child decides to use two potted green plants. He chooses the same kind of plant, in the same-sized pots, growing well in the same kind of soil; that is, he attempts to get plants as nearly alike as possible.

He allows one plant to continue to grow under ordinary conditions just as it has been doing. This is his control. He places the other plant in a completely dark place. Otherwise, he keeps conditions as identical as possible. The factor of light is the variable.

Periodically, he examines both plants. He notes and keeps a careful record of any changes that take place. At the end of ten days, dramatic differences have developed. Since all other aspects of the experiment are the same, the experimenter concludes that the differences may be ascribed to the difference in the amount of light available to the two plants. This is the answer to his question, "What would happen to green plants if there were no more sunlight?"

But this answer must be considered tentative only. It may not be the final answer. There is always the possibility that the results obtained were only accidental. Perhaps another plant kept in darkness would not react in the same manner.

He might try more than two plants—perhaps ten—keeping five in darkness and the rest in the light. He repeats the steps used earlier. At the end of ten days, he finds that the plants in the dark reacted in a similar manner to the one used in the first experiment.

If this happens, he has a sounder basis for his conclusion. Even so, he should check his conclusions with an authoritative source.¹

Not all situations call for experimentation. Many answers are to be found by direct observation of phenomena, by asking others, by reading books. Doing experiments when the answer is already known, not only by the teacher but by the students as well, is a dull and unproductive use of time.

¹ Gerald S. Craig and John Urban, *Teachers Manual for Science Today and Tomorrow: Facing Tomorrow with Science* (Boston: Ginn and Company, 1958), p. 12.

AUDIOVISUAL AIDS

Although personal, firsthand experiences furnish the richest ways for acquiring correct concepts in science, they are not always possible. Glaciers and geysers can seldom be visited. Hence the teacher seeks another source to help children learn about glaciers and geysers.

Often visual or auditory aids can be profitably used, such as colored photographs, slides, filmstrips, movies and recordings. Many schools now budget for the purchase or rental of such materials. Catalogs of major distributors of audiovisual materials should be available to teachers. Often the school librarian is custodian of the audiovisual aids, which are kept in the library and checked out as books are loaned.

Museums sometimes have dioramas and mounted exhibits to loan to neighborhood schools. Many commercial and industrial plants have exhibits that can be had for the charge of mailing them back to their owners. Models, such as a model of the human body, can be profitably used.

For example, in discussing geometrical shapes, children in a fourth grade had become interested in Pythagoras and the introduction of geometry into Greece. The name of Socrates was mentioned in answer to the question, "What other famous men lived in Ancient Greece?" Then it was brought out by the teacher that a favorite saying of Socrates was "Know thyself."

The children pondered on what "Know thyself" really meant. Someone suggested that it was important to know what is in our bodies, and this launched the class on a study of the human body.

Through much research in encyclopedias, trade books and many texts, children found that the smallest part of a healthy body is a cell. After initial total class discussion, individual and small groups of children worked on their own to delve into this study, under the guidance of the teacher. Various activities included:

Taking apart the large model of the human body (and putting it together again).

Learning about the bony framework, joints, and organs.

Writing reports and drawing figures.

As well as "knowing themselves," children developed vocabulary and research skills in their study of the human body.²

Perhaps one of the most exciting innovations now being used in schools is the tape recorder. There is no end to the possibilities for enriching classroom living through carefully prepared tapes. Recordings of talks by specialists in any number of areas can be made and re-used. Discussions of

² Highview School, Hartsdale, N. Y., Fourth Grade.

children concerning scientific matters are frequently worth taping and re-using, often as an evaluative device wherein children examine their own ability, or lack of it, to think critically. Recordings of bird songs, of sounds at a pond, of porpoises communicating in a tank, of animals when in danger are among other uses of tapes.

Needless to say, the same careful planning for using auditory and visual aids that characterizes uses of other materials is essential for the best results.

There are, then, many types of activities which can serve as channels through which boys and girls may learn science. The choice of the particular activity, or activities, depends upon the goals to be achieved. Whatever is chosen, that activity should promote understanding, interest and appreciation in science. It should make science concepts and principles more vivid, more clearly understood. As was said earlier in this bulletin, science experiences should help children construct a comprehensible and orderly system of explanations for natural phenomena and build a basis for intelligent control and utilization of the natural world.

THE UNIT*

Edward Victor

Edward Victor presents a comprehensive discussion of the key components of a planned and structured elementary science unit. These components include the overview, teacher's and pupil objectives, initiating activities, learning activities, materials, bibliography, vocabulary, culminating activities, evaluation, and work sheets. Dr. Victor describes the purpose of each component, and shows in detail how the components may be developed and incorporated into the unit. This excerpt on the unit is taken from Chapter 5, "Planning for Science in the Classroom," of Science for the Elementary School.

Concomitant with the need for planning is the need for organizing the elements of good planning into a suitable framework, through which the teaching-learning situation in the classroom has scope and sequence. A highly effective means of organizing such a framework is the unit.

* REPRINTED FROM *Science for the Elementary School*, 2nd Ed. (New York: The Macmillan Company, 1970), pp. 117-129, by permission of the publisher. Dr. Victor is Professor of Education at Northwestern University.

The unit is a logical division of class work or activity. When constructed, the unit becomes an *anticipated* plan for using a wide variety of activities and materials so that learning can take place. The objectives of the unit are to help the children learn science content and process, and to develop such behavioral outcomes as scientific skills, attitudes, appreciations, and interests. Thus, the unit presents a plan for providing learning activities that will achieve the objectives of the unit.

Sometimes beginning teachers are told that a good teacher does not have to plan the unit carefully and rather should try to build from questions, conversations, arguments, or other sporadic incidents that occur in the classroom. This method is not as simple as it may sound. Definite readiness is required for this kind of emerging lesson or unit. First, the teacher must have a competent science background so that she is familiar with the topic under discussion. Then the teacher must be acquainted with a wide variety of experiments, demonstrations, and other learning activities suitable for teaching the understandings associated with the topic. Finally, the appropriate supplies, equipment, references, and other materials must be easily or already available. Once the teacher has this background of science knowledge, activities, and materials, she is in an excellent position to convert questions and incidents into worthwhile learning situations. The same readiness is also necessary for experienced teachers. A science lesson or unit can emerge from incidents in the classroom only when the teacher has the necessary knowledge and tools to take advantage of the situation.

Construction of a unit entails careful planning and preparation, but the rewards are great, namely, effective teaching and learning. When units bog down or collapse, the failure is generally due to a lack of adequate planning and preparation. A very hastily prepared or poorly constructed unit will create "dead spots" in a learning situation, which cannot ordinarily be remedied by the teacher's ingenuity or ability to think quickly. When this situation occurs often—and sometimes one unfortunate experience suffices—the teacher is likely to reject all unit construction as a "waste of valuable time," and thus discards what is generally considered a most valuable and effective teaching technique.

Initial attempts to construct units are often slow and time-consuming, as are other valid teaching techniques when planned and presented for the first time. The teacher may spend a lot of time in finding the best sources for collecting the science concepts and learning activities, and an equal amount of effort in coordinating all the unit components into an effective working plan. However, once the pattern becomes familiar, the time and effort involved lessens considerably, and the results become increasingly satisfying and rewarding.

When planning and constructing the unit, the teacher or curriculum committee selects the objectives, develops the means for arousing pupil interest and problems, anticipates a logical sequence of learning activities,

provides for the necessary laboratory and reference materials, and even gives consideration to the possibilities for evaluating both the learning and the behavioral outcomes that the children will gain. The teacher or committee strives at all times to give the unit suitable scope and sequence.

The unit should never be rigid. It must be flexible enough to permit digression at any point, if necessary, without interrupting the broad pattern of learning anticipated by the unit. It is necessary to plan the day's work in advance, but the plan should be pliable enough to include and incorporate new situations and questions as they arise.

What to include in a unit is always a matter of discussion. Proponents of the various types of units differ somewhat about content and organization. However, it is generally agreed that a unit should contain most—if not all—of the following:

1. Overview.
2. Objectives.
3. Initiating activities.
4. Learning activities.
5. Materials.
6. Bibliography.
7. New science vocabulary.
8. Culminating activities.
9. Evaluation.
10. Work sheets.

A discussion of each of these components of a unit follows.

OVERVIEW

The purpose of the overview is to describe the nature and scope of the unit. Some teachers or school systems, when constructing units, omit the overview. However, the overview can serve a definite purpose. When a school system develops a science program and constructs units, it is likely that a science committee is given the responsibility of preparing the units for the rest of the teachers in the school system. This preparation will result whenever a school system is large and has so many elementary school teachers that it becomes impossible to involve all the teachers in constructing every unit for each grade level. Furthermore, with the consistent rapid turnover of elementary school teachers, there will always be new teachers or beginning teachers who have started teaching after the units have been constructed. In such cases, whenever units are presented to teachers who have had no part in constructing them, it is always helpful to provide an overview with a brief description of the nature and scope of the unit. Even when the teacher makes her own unit, an overview can be of real service when shown to administrators, parents, or other teachers who visit her class and need a quick briefing on what is going on.

One highly effective way of presenting an overview is to give it in written form, consisting of two or three paragraphs. The overview might begin by describing the importance of the unit topic in our daily lives, for both child and adult. Then it might list the key concepts, and conclude by giving some general values and desirable behaviors that the children will derive from the unit.

An example of this kind of overview, for a unit on "Leaves," is as follows:

Leaves are important to the daily life of both children and adults because they are one of the primary sources of food for all living things. Leaves and grass contain chlorophyll and can manufacture food, and from green leaves and grass we get all our food—either directly or indirectly. Hence, the study of leaves can be basic to the understanding of life and how it exists on earth. In addition, leaves give us one of the several signs of the change of seasons in many parts of the country.

This unit hopes to teach (1) the kinds of leaves and how they differ from one another, (2) the parts of the leaf, including its external and internal structure, (3) the function of the leaf, with special emphasis on photosynthesis, and (4) the change in color of leaves in the fall.

From the learning activities in this unit the children may gain a better understanding of leaves and their function, and an appreciation of the beauty and the way leaves are constructed. The children will develop further their ability to observe carefully and accurately, to listen intelligently, and to read science books for information. They will be asked to draw conclusions from what they have learned, and to apply these conclusions to life situations. Finally, they will learn how to express themselves more effectively, to participate more ably in class discussion, and to work cooperatively with their peers.

TEACHER'S OBJECTIVES

In general, the teacher has two main objectives: (1) to help the children learn science content—the product of science, and (2) to help the children learn the key operations of science and the scientist—the process of science. Both objectives are vital, and one is meaningless without the other. Consequently, definite provision must be made to incorporate both objectives into the unit. Otherwise the unit will fail to accomplish its purpose.

Some school systems develop only a scope and sequence chart, leaving the construction of units to the individual teacher. Other school systems appoint a science curriculum committee, which, under the guidance of a science supervisor or consultant, constructs a comprehensive set of units for all the teachers. An analysis of science units which have proven to be highly successful, and which have enabled the teacher to achieve effective learning in the classroom, shows that they all have one factor in common. In all cases, the units contain an outline or list of the science concepts that the children are expected to learn while the units are in progress. And it

seems that the more detailed the outline or list, the more successful are the units.

The preparation of an outline or list of concepts for inclusion in the unit helps the teacher in two ways. First, regardless of whether the unit is constructed by the teacher or by a committee, such an outline can be of great help as a guide when the learning activities are selected for the unit. Second, the outline serves as a check to make sure that the teacher will have the necessary science background for the topic being studied.

If the teacher's school system has a detailed curriculum guide, she will have some indication of what science concepts to teach. If there is no such guide, the selection of concepts will have to be left to the judgment of the teacher. In this case she may have to simplify the wording of these concepts (without losing their scientific accuracy) to meet the vocabulary level of her class, and organize them into what she thinks will be a logical sequence of learning. The latter is very important because one set of understandings will lead easily into another set of understandings, and in this way learning can take place more quickly and efficiently.

The learning of science content, then, is one of the teacher's two major objectives. The second major objective is the learning of science process, accompanied by the development of desirable behaviors. These behaviors include scientific skills, attitudes, appreciations, and interests. They also involve how to think critically and creatively, and how to solve problems. These behaviors emerge from the learning activities that are conducted while the unit is in progress. The behaviors may be either immediate or long-range behaviors. Examples of these behaviors have already been described in Chapter 2, "Objectives of Elementary Science."

The learning of process and the development of behaviors will depend to a large extent upon the kinds of learning activities that will be selected. Each learning activity, as a rule, will call for the use of certain operations and the development of certain behaviors. Consequently, if process is to be taught effectively, the teacher must become completely familiar with all the key operations of science and the scientist and with all the desirable behavioral outcomes. The teacher can then examine each learning activity closely to determine which operations and behaviors are associated with that activity. Provision for the inclusion of a wide variety of learning activities in the units will ensure ample opportunity for the children to develop proficiency in any or all of the desired operations and behaviors.

Many units include a list of those key operations and behaviors that will constitute one of the objectives for the unit. These operations and behaviors should be clearly expressed in specific behavioral terms that lend themselves to proper observation and evaluation. In some units the operations and behaviors are written in the form of statements. In other units they are written as questions.

PUPIL OBJECTIVES

Units often include pupil objectives. These objectives are the anticipated pupil questions or problems that will emerge from the initiating activities. The questions and problems are stated as the children might raise them in the children's own vocabulary. Pupil objectives thus also remind us that the children's aims may be quite different from those of the teacher. The teacher may want the children to learn about heat expansion. The children, however, will want to know why cracks are intentionally put into concrete sidewalks. The teacher is interested in electrical circuits; the children want to learn how to connect a dry cell, wires, and a porcelain socket containing a bulb so that the bulb will light up. The teacher is interested in the laws governing vibrating strings; the children want to know what can be done to make the musical note from a violin or guitar higher or lower. The teacher is primarily concerned with the learning of basic science information and the development of desirable behaviors. The children want to know "why," "what," "how," "when," "what will happen if," and so forth.

If the initiating activities are properly selected, the pupil objectives will emerge easily. However, because the pupil questions and problems in the planned unit are anticipated, if the children should fail to raise them, the teacher may ask them instead. Actually, the children often raise better or more questions and problems than those anticipated by the teacher. The wise teacher incorporates these questions and problems into the unit.

INITIATING ACTIVITIES

The purpose of initiating activities is to involve the children in the unit; these activities are the means whereby pupil interest and curiosity are aroused. In the process, questions and problems are raised that, when answered or solved, will help achieve the teacher's objectives. The main purpose of initiating activities is to raise questions or problems, the answers to which the children do not know but will find out as they proceed with the learning activities in the unit. Because the children do not know the answers, their curiosity is piqued and their interest in finding out the answers is aroused.

GENERAL OR OVERALL INITIATING ACTIVITY. Usually a general or overall initiating activity is used to introduce or "initiate" the entire unit to the children. There are several ways of initiating the entire unit. Sometimes a previous unit will lead the children quite naturally into a new unit. If the class has just finished a study of magnets, for example, it will require very little effort to motivate the children for the study of electromagnets. Units can also be initiated by books and stories. Sometimes, merely the announcement of the next topic or problem may be sufficient to arouse pupil interest and problems.

Another way to initiate a unit is to set the stage for the unit. A good example is an attractive bulletin-board display, accompanied by thought-provoking questions. To initiate a unit on "Evaporation and Condensation," a teacher may plan to put on the bulletin board a series of pictures showing evaporation and condensation taking place. This display can include pictures of a puddle of water on a concrete sidewalk under the warm sun, sheets or towels drying on the clothesline, droplets of water on a bottle of soda pop or on the sides of a pitcher of lemonade, fogged-up windows, a person's breath visible on a cold, wintry day, and so on. Under the pictures can be questions such as "How does the water get into the air?" "How does water come out of the air?" "How can we make water go into or come out of the air more quickly or more slowly?"

Another way to set the stage for a unit is to have a display of materials on a table with accompanying questions. Materials for display can include pictures, books, models, or specimens. When initiating a unit on leaves, it will be natural to have a variety of leaves on display, especially in the fall. Typical questions that can be asked would be "Are these leaves alike?" "How are they different?" "How many parts does each leaf have?" "What do leaves do?" "Why do leaves change color in the fall?"

A thought-provoking demonstration is an excellent way to initiate a unit. A teacher can initiate a unit on "How Does Heat Travel" by simply placing a spoon in a cup of hot water. Pupil interest and curiosity will be raised about why the part of the spoon that is out of the water also becomes hot.

Even a thought-provoking discussion can initiate a unit. In temperate climates most children are quite familiar with the effects caused by static electricity, especially on a cold, dry day. The teacher can initiate a unit on such a day by first asking the children to describe personal experiences with static electricity and then leading into an on-going discussion about the characteristics of and reasons for this phenomenon.

INITIATING ACTIVITIES DURING THE UNIT. There are some who believe that one good general or overall initiating activity is sufficient to sustain pupil interest and motivation for the entire unit. They feel that the one activity will raise enough questions and problems to ensure the learning of all the science content and process in the unit. On the other hand, there are many who think that additional initiating activities are necessary as the unit progresses. These additional activities may be necessary, especially when a unit extends over two, three, or even more weeks. Interest and motivation may flag over a period of time for even the most enthusiastic children.

Also, in those units which include an outline or list of science concepts, the concepts seem to arrange themselves into related groups. These groups differ sufficiently among themselves to have their own initiating activities. Thus, the unit will need enough initiating activities to raise pupil questions or problems involving all the understandings involved in the outline or list

of science concepts. Usually one initiating activity is needed for each group of related concepts.

Thus, additional initiating activities—other than the general or overall initiating activity—may be used at various intervals as the unit progresses. The most effective activities are thought-provoking experiments and demonstrations, questions or series of questions, and discussions. Occasionally, one or more frames of a filmstrip can be used as an initiating activity. Often the general or overall activity can also be used as the initiating activity for the first group of related understandings in the outline or list of concepts.

Films, field trips, and speakers should rarely be used as initiating activities. The purpose of initiating activities is to raise questions or problems, the answers to which the children do not know, which then necessitates special learning activities to find the answers. Films, field trips, and speakers as a rule not only raise questions, but also usually provide the answers to the questions immediately afterward. This procedure defeats the purpose of the initiating activity.

Similarly, because the initiating activity raises questions instead of giving answers, the initiating activity is almost never used as the first learning activity. The purpose of the learning activity is to obtain answers whereas the initiating activity is designed only to raise questions. However, the initiating activity can be used to advantage as an evaluative technique later in the unit. If the children have really learned the science understandings in the subsequent learning activities, they should now be able to answer the questions or solve the problems raised by the initiating activity.

The selection of good initiating activities is perhaps the most difficult phase of unit construction. Very often, many pupils are able to explain what were intended to be thought-provoking experiments or demonstrations. Thus, the initiating activities have not fulfilled their purpose and are valueless. The curriculum committee or teacher should not become discouraged, but must discard the unsuccessful initiating activities and continue to search for new and better ones.

LEARNING ACTIVITIES

Learning activities are the means by which the children learn both the content and process of science. The children acquire understandings that enable them to answer the questions or problems raised by the initiating activities, gain proficiency in performing the key operations of science and the scientist, and develop desirable behavioral outcomes. The teacher uses a wide variety of learning activities in the unit to accomplish this purpose. All the techniques and activities suggested in Chapter 4, "Methods of Teaching Science," are utilized. These include experiments, demonstrations, observation, reading and study, discussion, oral and written reports, films, filmstrips, speakers, models, charts, posters, planning, and so forth.

Many teachers have a tendency to use many more learning activities than are necessary to ensure satisfactory learning. This excessive use tends to prolong the unit unnecessarily, slow down learning, and dull pupil interest. The experienced teacher employs her learning activities wisely and economically, especially when teaching for science understandings. She realizes that sometimes one activity is enough for an understanding to be learned. Occasionally one good learning activity will suffice to produce the learning of more than one understanding, especially if the understandings are simple or are related to each other. Other times, when an understanding is difficult or abstract, more than one activity may be necessary to obtain adequate learning. Slow learners usually learn better when more than one activity is used.

The grade level may also influence the number of learning activities needed. In the lower grades, where the children's attention span is small and their ability to think abstractly is not well developed, more than one activity is often necessary to obtain satisfactory learning of an understanding. However, in the upper grades one well-chosen activity is usually sufficient.

In all cases the best procedure is for the teacher to use as many—but *only* as many—activities as are necessary to ensure satisfactory learning. And if the teacher finds that there is a surplus of activities, they can always be used as additional activities for slow and fast learners.

MATERIALS, BIBLIOGRAPHY, NEW SCIENCE VOCABULARY

Units usually list all the materials that will be needed for the learning activities. This list includes supplies, equipment, textbooks, reference materials, films, filmstrips, and other learning aids. In this way the teacher can begin to accumulate the necessary materials and have them ready and available as the activities require them.

Most units contain a bibliography of the textbooks and other reference materials that will be used during the unit. This bibliography includes materials for both the children and the teacher. The pupil list contains those references that the children will use to answer questions, solve problems, learn how to do an experiment, check conclusions, and find additional information for reports, and so forth. Wherever possible, the pupil list should include duplicate references on the same topic, but on different grade (reading) levels. Thus, there will be available reading materials for slow and rapid learners. The teacher list should contain those references that will provide the teacher with more detailed information about the science topic or about the experiments and demonstrations the teacher plans to conduct.

For clarity, the pupil and teacher references should be listed separately. Each reference should include the title, author(s), publisher, place and date of publication, and grade level (if it is part of an elementary science

textbook series). Films and filmstrips should be included in the bibliography, usually under a separate listing. Besides listing the title and the producer, it may be helpful to include such information as the running time, whether it is in black and white or color, and so forth.

With the development of concepts and understandings, the children regularly will encounter new words and terms. This new vocabulary must be thoroughly explained and understood for maximum learning to take place. Many units include a vocabulary list of the new science terms that will be learned and used during the unit. This list reminds the teacher to give full attention to the learning of the terms when they appear for the first time.

CULMINATING ACTIVITIES

A culminating activity is an activity that concludes the unit. It should be a logical part of the unit and a natural outgrowth of the work in the unit. It should appear when the objectives of the unit have been achieved. The culminating activity helps summarize the learnings and brings the high points of the unit into focus.

Culminating activities can be many things. They can be films, filmstrips, field trips, or speakers. They can be exhibits, science fairs, news letters, or reports. They can even be discussions, programs, assemblies, or dramatizations. However, the teacher should always keep in mind that culminating activities are primarily for the benefit of the children, even though others may profit from them as well.

Certain precautions should be noted about the use of culminating activities. They should not try to summarize every science understanding in the unit because this procedure would make the activity much too long, with the resulting loss of interest and educational value. Not every unit needs a culminating activity. Some units do not lend themselves well to such activity, and to have one arbitrarily would make the activity highly contrived and artificial. Also, sometimes a culminating activity can actually hinder the children from continuing quite naturally to another unit. Finally, tests and other evaluative techniques are not culminating activities and should not be used as such.

EVALUATION

Evaluation should be continuous while the unit is in progress. The teacher must determine how well the children have learned science content and process and have developed desirable behavioral outcomes. Since evaluation is an ongoing continuous process, it is impossible to complete the evaluation section of a pre-planned unit. However, the unit can indicate the kinds of evaluation techniques that may be used while the

unit is in progress. It can also indicate specific places in the unit outline where the learning activities lend themselves particularly to the development of certain behaviors.

The children themselves can—and should—participate in much of the evaluation. They can evaluate their work, their daily progress, and their learnings and behaviors as well. The various techniques for evaluation that can be used by both teacher and children are described in Chapter 8, "Evaluation of Science Learning in the Classroom."

WORK SHEETS

When units are constructed, careful consideration must be given to how the work of the children and teacher will proceed. Once the unit is in progress all the components of the unit must be coordinated and utilized to achieve maximum learning. At the same time provision must be made for evaluation of the work that is being done. Consequently, the working period is the vital part of the unit and, as such, must be thoroughly integrated. For in the working period lies the success—or failure—of the unit.

There are several forms in which the working period can be presented. Of these forms, two are most commonly used and both involve work sheets. One form makes use of a single running column. This single column contains in varying order of sequence the science concepts, initiating activities, anticipated pupil questions or problems, learning activities, culminating activities, necessary laboratory and audio-visual materials, and reading materials for the teacher and the children.

In the other form all the unit components are placed in a varying number of parallel columns. In these parallel columns the corresponding science concepts, anticipated pupil questions, learning and culminating activities, laboratory and audio-visual materials, teacher and pupil bibliography, and even evaluative techniques are all placed side by side. By using adequate spacing in the parallel columns, the work sheets provide the teacher with a horizontal row of related components, all clearly delineated.

KINDS OF UNITS

When looking for guides or models for constructing units, the local curriculum committee or teacher will encounter in the literature what seems to be a large variety of units. Curriculum experts, all interested in good teaching and learning, have proposed or described units with the following names: teaching units, experience units, resource units, problem units, activity units, textbook units, center of interest units, topical units, survey units, and so forth. To add to the confusion, the term *unit* has

become so popular that teachers use it very loosely to describe almost any kind of teaching-learning situation.

However, a closer examination of these units will reveal that many are quite similar, differing in varying degrees with regard to style or format. Accordingly, all these units can be classified into one of three basic kinds of units: resource units, teaching units, and textbook units.

PROGRAMED LEARNING—A USEFUL TOOL FOR THE SCIENCE EDUCATOR*

William B. Reiner

Programed learning is one of the newer techniques being offered as a means of more effective science instruction. Because of the interest and extensive experimentation in this technique, this article is intended to offer some guidance in understanding and evaluating the various aspects of programed learning. William B. Reiner defines programed learning as the arrangement of the materials to be learned, in graded steps of difficulty, in such sequence and in such manner of presentation that will result in the efficient rate of understanding and retention.

Recent developments in psychology, communication theory, and technology have advanced the science and art of programed learning and teaching to unexpected levels of efficiency. Much study and new developments are being invested in programed learning; much more remains to be done. Despite the exaggerated claims by salesmen of teaching machines, there is sound reason for optimism in the future of programed learning and teaching. The heart of automated teaching or programed learning is the program. Some of the psychological and educational principles employed in constructing the programs which are used in "teaching machines" will be discussed in the sections which follow. Sections of programs concerned with teaching science will be used to illustrate the "how" and "why" of programed learning. Included also is a purchaser's guide to science programs.

At this point certain terms should be defined for the guidance of the

* REPRINTED FROM *The Science Teacher*, Vol. 29, No. 6, October 1962, pp. 26-33. Copyright, 1962, by the National Science Teachers Association, Washington, D.C. Reprinted by permission of the author and the publisher. Dr. Reiner is Professor of Education at Hunter College, New York.

reader. A *Program* is the subject matter to be learned by the pupil. *Programed Learning* is the arrangement of the materials to be learned, in graded steps of difficulty, in such sequence, and in such manner of presentation that it will result in the most efficient rate of understanding and retention.

Programming is the process of arranging materials to be learned by the student into a series of steps carefully plotted for logical or psychological sequence and meaning, from the concrete to the abstract, from the familiar to the new, and from fact to concepts. Competent teachers have long followed the principles implied in the above definitions. They have planned instruction and have implemented their teaching by asking questions and reacting to pupils' answers.

What, then, makes programed learning different? The answer is that it consists of a system which makes it possible to accomplish the important critical functions of teaching without the presence of a "live" teacher. A learner, a program, and a device to present the program (not necessarily a machine or gadget, special books or cards will serve, too) constitute a basic programed learning system.

Although machines are useful, and in some types of systems even necessary, the program is the heart of the matter of programed learning. While the machine or "hardware" is an auxiliary device, the glamour of automation and technology has given the headlines to gadgetry, consigning to the back pages top-level psychological research which has advanced programed learning, sometimes called automated learning, to its present levels of acceptance.

The principle of immediate reinforcement is the psychological basis upon which programed teaching rests. Reinforcement, in terms of the classroom, is getting the right answer or praise from the teacher, or a good grade, or the approval of classmates, and other satisfactions. In terms of programed learning or the teaching machine, it means getting the correct answer to the question presented to the pupil by the program. The guidance, satisfaction, and assurance of knowing immediately how well he has done enables the pupil, in general, to learn faster and retain better. There is no doubt as to the scientific soundness of the principle of reinforcement, though there may be about the teaching value of some of the programs based on the principle. Countless experiments with animals and human beings have proved the principle. F. Curtis and G. Woods in their paper "A Study of the Relative Teaching Values of Four Common Practices in Correcting Examination Papers" in the *School Review* of October 1929 showed that pupils who obtained their test results immediately achieved better in science classes or courses.

BRIEF VIEW OF TEACHING MACHINES

A teaching machine is a device that presents a program and requires the pupils to respond to the questions. The difference between a teaching

machine and an ordinary audio-visual device is that the teaching machine requires an answer and usually the pupil writes or speaks it into the machine. A sound film or tape player is not classified as a teaching machine because normally the pupils are not required to give answers to the materials it presents.

A teaching machine has several recognized functions. The following are listed by Finn and Perrin¹ as basic:

1. Used for individual instruction.
2. Contains and presents program content in steps.
3. Provides a means whereby the student may respond to the program.
4. Provides the student with immediate information of some kind concerning his response that can act as a psychological reinforcer.
5. Presents the frames of the program individually.
6. Presents the program in a predetermined sequence.
7. Is cheat-proof.

The following are listed as additional functions:

8. Discriminates correctness of response.
9. Automatically advances program.
10. Provides random access to program frames allowing for branching.
11. Memory function holds out frames on which error has been made for further presentation.
12. Records results.
13. Selects program items based on evaluation of previous responses.
14. Permits two-way communication between student and machine (typewriter-computer).
15. Stores complete programs and responses.

With allowance for physical refinements and variations such as sound, film, electric power, and so on, a machine works as follows:

1. It exposes a single frame on which is presented a single step or problem for the pupil to study. It also has a question, a problem, or an exercise for the pupil to answer. In brief, a frame is a question-answer segment of a program.
2. The pupil indicates his answer to the problem on the space provided. Some machines are adapted to allow a limited time for the pupil's response.
3. The machine lets the pupil know whether or not his response is correct. If he is wrong, he usually can make another try.
4. Most machines record the number of correct answers or errors, and some distinguish the types of errors made.

¹ J. D. Finn and D. G. Perrin, *Teaching Machines and Programed Learning*, 1962: *A Survey of the Industry*. Occasional Paper No. 3. Technological Development Project, National Education Association, Washington, D.C. 1962. p. 18.

5. The teacher need not be present while the student is working out his program. This allows greater flexibility for the teachers and pupils.

PROGRAMING TECHNIQUES

S. L. Pressey, B. F. Skinner, and N. A. Crowder are prominent names among the pioneers and developers of program techniques. The philosophy of each in regard to programed instruction is briefly presented below.

Pressey considered teaching programs to be a supplement to textbooks not a substitute. Teaching machines were quiz devices, adjuncts to testing which helped consolidate materials previously learned in textbooks, lectures, or a laboratory. Pressey's devices employed principles which most psychologists agree are essential to achieve effective learning; namely, the continuous active state of the pupil in answering questions, the reinforcement when the pupil is immediately informed as to the correctness of his response, and the progress of the pupil individually and at his own rate. Pressey employed the multiple-choice type of question. If an incorrect answer were given, a student could be referred to a correct source of information and could return later to answer the question. This type of program is called "branching" because the pupil's activity branches out from questions to learning materials (to get the correct answer) and back to questions. This is a sharp contrast to "linear" programing which employs an unbroken sequence of questions and answers.

Skinner believed that "reinforcement" was the primary basis of programed learning. The main objective was to bring pupil behavior under control of a variety of stimuli. By developing the subject matter in very small steps in each frame, the success of the pupil reinforces him. Frequently the information asked of the pupil in the frame is merely verification of some simple information he has learned. As he progresses, he is rewarded by his correct responses and as a result is highly motivated. Skinner's technique is in closer accord to the concept of programed learning because of the tight, unvarying, carefully constructed sequence of questions and answers in each frame. This is called the linear type of program.

Schematically, the sequence of items in a linear program appears as follows:



Item 2 with its information would have to follow 1.

In a branching type of program there would be diversion and intermediate steps if the student had to look up information before he could go from Step 1 to 2 and from 2 to 3. Conceivably, he might have to back track from 3 to 2 to make sure he knew what he was doing.



Crowder is closely associated with intrinsic programing in which multiple choice items are employed. The errors made by the pupil in answering questions are used to build knowledge and skill. The pupil is referred to correct sources of information so he can eliminate the mistake and proceed. This branching procedure resembles the blind alley in a maze, except that the learner is given a specific direction to help him find his way when he meets an obstacle. Intrinsic programing requires a clear anticipation of how pupils think. (Every experienced teacher uses this approach in classroom teaching!) Although the format of questions and answers in the frame can be quite flexible, two requirements must be followed. The items must be two or more choices to be answered and the incorrect answer should result in directing the pupil to materials or information which will correct him and guide him back to the correct program sequence.

Branching is a teaching technique that is familiar to teachers who have elicited answers from pupils by cogent reasoning and well-conceived questions. For example, in a laboratory experience, a pupil unable to explain why sugar changes to porous carbon after being treated with concentrated sulfuric acid is guided by a series of questions and helpful hints until the correct response has been developed. It takes a masterful teacher to anticipate the errors and strengths of pupils to do this on a face-to-face basis. To program this teaching process on paper, so that a pupil can experience similar learning, requires great insight and verbal artistry. In short, good programing ability is a highly developed skill. Space limitations preclude the inclusion of a sample of a branching program.

A linear program which develops some facts and concepts about measuring temperature is given below. It is part of a program developed by the staff of the New York Institute of Technology, New York City, under Alexander Schure. Each information segment, question, and answer constitute a frame of a section, "The Weatherman's Measurements." Note the economy of learning which Figure 1 contributes to the development of the idea. Information as well as simple skills in reading a thermometer is developed.²

One of the most important measurements that the weather forecaster must know is the temperature of the air. As you know from observations made in your own home, temperature is measured by an instrument called a (thermometer) A thermometer is a glass tube with a bulb at one end filled with

² *The Wonders of Science*. "A Learning Program." Educational Aids Publishing Company, Carle Place, New York, 1962.

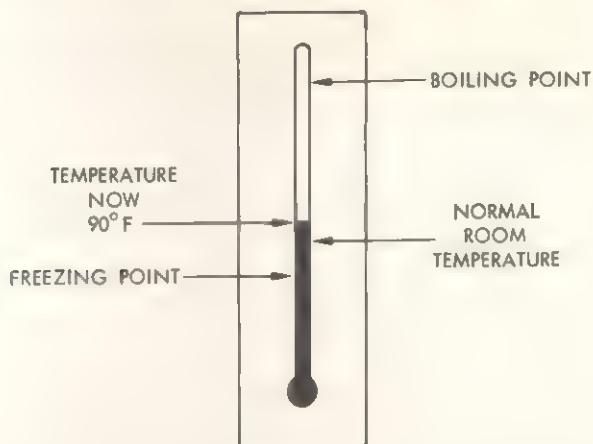


FIGURE 1.

The above diagram may be repeated in each subsequent frame of the illustrated linear program designed to develop certain concepts.

a, such as mercury or alcohol. (*liquid*) As the temperature changes the length of the column of the liquid in the tube rises or falls. As the temperature goes up, the liquid in the tube (*rises*)

You read the temperature from a scale marked right on the tube or alongside it. Temperature is marked in degrees Fahrenheit. When you say, on a hot summer day, that it is 90 degrees in the sun, you mean that the temperature is 90 degrees (*Fahrenheit*)

The temperature would be abbreviated 90° F. A thermometer with several important markings is illustrated. Note that the present temperature as read by the thermometer is (*90° F*)

From the marking on the scale it is clear that normal room temperature is much on the scale than 90° F. (*lower*)

For scientific purposes, normal room temperature is taken to be 68° F. On a normal day at sea level, water freezes at 32° F. We say that the freezing point of water under these conditions is 32° F. The point is abbreviated as in the diagram. (*FP*) At the opposite end of the scale we see the letters "BP." Water boils at 212° F. Thus the abbreviation BP must represent (*boiling point*)

A widely accepted type of program is known as Ruleg (combined from the words "rule" and "example"). This program consists primarily of rules and examples which the pupil is asked to match. For example, a rule is given and then the pupil must fill in an example which illustrates it. In Table 1 some illustrations are given for various types of problems. The abbreviation "ru" is for rule, "eg" for example. A tilde (~) over the symbol means incomplete, a bar (—) means negative. The column "Class" indicates varieties of combinations of questions based on rules and examples. The answers are given in the right-hand column.

TABLE 1

Skinner's High School Physics Program Reconstructed According to the Ruleg System

Class	Sentence to Be Completed	Words to Be Supplied
ru+ẽg	1. To "emit" light means to "send out" light. For example, the sun, a fluorescent tube, and a bonfire have in common that they all send out or light.	(emit)
ẽg	2. A firefly and an electric light bulb are alike in that they both send out or light.	(emit)
ru+ẽg	3. Any object which gives off light because it is hot is called an incandescent light source. Thus a candle flame and the sun are alike in that they both are sources of light.	(incandescent)
ẽg	4. When a blacksmith heats a bar of iron until it glows and emits light, the iron bar has become a(n) source of light.	(incandescent)
ẽg	5. A neon tube emits light but remains cool. Unlike the ordinary electric light bulb, then, it is not an of light.	(incandescent) source
ũ	6. An object is called incandescent when	(it emits light because it is hot)
ru+ũ	7. It has been found that an object, an iron bar, for example, will emit light if its temperature is raised above 800 degrees Celsius. Therefore we say that above, (temperature) objects will become	(800° Celsius) (incandescent)

A. A. Lumsdaine and R. Glaser. *Teaching Machines and Programed Learning: A Sourcebook*. Department of Audio-Visual Instruction, National Education Association, Washington, D.C. 1960. p. 491.

PROGRAM PURCHASER'S GUIDE

Programs in science are becoming available in greater quantities. What program(s) shall a school or department buy is a frequent question.

Several guiding questions for purchasers are given in the October 1961 issue of *Programed Instruction*.³ The questions are similar to those needed to decide to buy textbooks or equipment.

1. Is the content (material) appropriate?
2. Is the content well programed?
3. What have the students learned from the program?
4. What are the characteristics of the student population(s) involved in the trial run?

In 1961, the American Educational Research Association, the American Psychological Association, and the department of Audio-Visual Instruction of the National Education Association issued a series of guide lines for users of automated teaching devices.⁴ The guide lines point out that just any set of question and answer materials does not make an acceptable program. There should be appropriate goals and content and good question development carefully planned.

³ *Programed Instruction*. The Center for Programed Instruction, Inc., 365 West End Avenue, New York 24, N.Y.

⁴ "Keeping Abreast in Education," *Phi Delta Kappan*, 11:145. December 1961.

TEAM TEACHING IN THE ELEMENTARY SCHOOL: IMPLICATIONS FOR RESEARCH IN SCIENCE INSTRUCTION*

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In this article seven basic assumptions about the efficacy of the self-contained classroom are challenged by the team-teaching approach to instruction of children. The authors define team teaching as an effort to improve instruction by the re-organization of teacher personnel, involving

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the assignment of two or more teachers to a group of pupils. This reorganization forces new roles for teachers, ranging from specialist to observer. Two models of team teaching are described, and the impact of the team teaching approach on curriculum organization and sequence and on grouping for instruction is discussed.

For many school systems team teaching has become more than an enticing phrase: many communities have now initiated the utilization of new personnel patterns to which the label "team teaching" might be applied. Generally, the organization of these various teams has consisted of a group of two or more teachers working together, within or without a formal hierarchy, to plan for, initiate, accomplish, and evaluate the instruction of the same group of children.

Before introducing two models of team teaching and some of the problems which need to be researched, the structure of the self-contained class will be examined. It is hoped that this review will help clarify some of the assumptions which new personnel organizations are now challenging.

SELF-CONTAINED CLASSROOM ORGANIZATION

In the self-contained classroom organization, the elementary school principal assigns twenty to forty students to a class, either homogeneously or heterogeneously grouped. If homogeneous, the assignment is usually on the basis of I.Q. and/or reading ability. The principal is also responsible for the supervision of all the teachers in the building and for curriculum coordination, pupil discipline, and public relations.

The elementary school class itself is usually under the direction of one teacher who provides instruction in the four basic areas of the elementary school curriculum: language arts, social studies, mathematics, and science. Teachers are expected to have knowledge and skills in all of the major areas and, furthermore, to be equally enthusiastic and competent in their presentation of each subject. They are expected to provide for a wide range of individual differences; this is usually accomplished by dividing the class into three groups: "high, average, and low." The teacher is also responsible for many non-teaching duties such as lunchroom supervision, bus duty, collecting milk money, and other tasks of a similar nature. The beginning teacher, just out of college, assumes *full* responsibility for her class; she assumes as much responsibility for instruction as teachers who have been teaching for twenty years. There is little chance during the school day for communication between this beginning teacher and teachers with many years of experience. The only time for extended communication is during the noon hour or before and after school.

Within the structure of this organization there is no career pattern for the young teacher who aspires to increased responsibility, increased prestige, and increased salary. Since all teachers are on the same salary schedule, which calls for increments on the basis of education and longevity of service, there is usually no provision made for higher salary based on increased responsibility. In this situation there seems to be no career pattern within the teaching profession for those who wish to remain in the classroom. If a teacher is seeking increased prestige or more responsibility, he usually moves into the field of administration. This removes him from actual teaching which, hopefully, is the reason he initially entered the profession.

ASSUMPTIONS CHALLENGED

The following are seven basic assumptions which are being challenged by the team teaching model:

1. That all teachers are approximately of the same quality, with the result that the superior teacher never moves (as teacher) to a position of greater influence over a large number of learners.
2. That each teacher should enjoy individual instructional autonomy; that is, that he has a right to be an absolute "king of his classroom."
3. That the assignment of differential reward and status leads to poor morale and lower productivity.
4. That the employment of part-time and/or sub-professional personnel will somehow have undesirable effects.
5. That the ideal class size approximates thirty.
6. That pupils can relate to only one teacher.
7. That values accrue from having one teacher teach all subjects.

DEFINITION OF TEAM TEACHING

Team teaching, as we envision it, is an effort to improve instruction by the reorganization of teaching personnel. It involves the assigning of two or more teachers to a group of pupils. This involves different schedules for teachers as well as changed allocations of time and space for instruction. It eliminates the rigid grouping based on one or two criteria and allows for variations in student grouping depending upon the outcomes being sought. It allows for teachers to observe other teachers teach the same group of learners. It *forces* teachers to communicate in planning for the same group of learners. It allows for a variety of period lengths, sub-groups, and part-time teachers with special competencies, as well as for programmed instruction. Evaluation of students is based upon the common observations of several teachers. Team teaching, furthermore, encourages teachers

to become specialists in one or more areas. The particular model which we are researching provides for a hierarchy of positions which are based on expertness and responsibility. It allows for increased salary and prestige accompanying greater knowledge and responsibility. The model also provides for the use of non-professional help as well as for the use of part-time professional help, lay readers, and other individuals who might aid in the learning process.

DIFFERENT ORGANIZATIONAL PATTERNS

There are several types of organizational structures built on different value systems. We shall discuss two of them.

1. Two "master" teachers (at increased salary) plus one teacher-aide are assigned to a group of seventy-five pupils. In order to keep the cost stationary the teacher-aide is employed instead of a third regular teacher. In the self-contained class structure, the ratio of teacher to pupil is approximately one to twenty-five, the same as above. Thus, by rearranging the budget, we are able to pay additional salary to the two teachers and still have funds with which to pay the salary of the aide. Implied in the value structure of this organization is that the cost will not be greater to operate a team teaching school than it was to operate a traditional school.

Among the duties of the teacher-aide is the assistance of pupils as they work individually. A variety of lessons are taped, programmed or individualized, so that pupils can work with a minimum of verbal teacher direction. The teacher-aide, a semi-professional person, circulates among the pupils to answer questions and offer any necessary help. In addition, she helps with such details as typing worksheets, collecting milk money, and supervising the playground.

2. A second organizational structure necessitates a higher budget. This model assigns six teachers and one teacher-aide to approximately one hundred and fifty children. The team is organized on a hierarchical basis. At the top is the Team Leader who receives \$1,000 to \$1,500 more than the regular teacher. This additional salary is given for increased responsibility as well as greater competency in an area of instruction.

On this same team there might be one or more Senior Teachers who receive from \$500 to \$1,000 more. These individuals have acquired competency in one or more subject fields. Usually both Team Leader and Senior Teacher have had three to five years of teaching experience in the elementary school.

The regular teachers on the team are trained elementary school people capable of teaching the normal elementary school curriculum. They usually teach in all of the subject areas, but begin to specialize in one or two if they aspire to become Senior Teachers.

The teacher-aide has the same type of responsibilities mentioned in the previous organization.

In the ideal situation, the Team Leader and Senior Teachers would complement each other by having competencies in different areas. In addition, these people should be capable of curriculum development in their particular strengths; of giving in-service education to members of their team; of supervising classroom interaction between teacher and pupil; and of aiding in the articulation of their subject area with others. Thus we have a small "school of education" built into the team.

The total school program is coordinated by the principal who heads two cabinets: an *administrative* cabinet composed of the Team Leaders which is responsible for policy decisions; and an *instructional* cabinet composed of the Team Leaders, Senior Teachers, and other specialists in the school, which coordinates and integrates the total school curriculum.

INSIGHT AND IMPLICATIONS

During the past two years, the authors have been engaged as science consultants and research personnel to work with the staff of a Lexington, Massachusetts, team teaching elementary school organized along the lines mentioned in pattern 2. Although it is felt that our short experience with team teaching does not, and cannot, entitle us to make any definitive statements as to what can and cannot be done, how certain tasks should be performed, or how specific problems should be solved, it has provided us with a number of problems and questions necessitating serious soul-searching on the parts of both ourselves and the teachers involved. Comparisons are still being made between this school and a control school in the same town, but evaluation is far from complete with so many problem areas still to be resolved.

While we have encountered many problems in our work so far, many seemingly inherent in a personnel structure where it is both *necessary* and *desirable* for a number of teachers to work closely together, the problem areas outlined below are unquestionably crucial ones for the instruction of science within the team teaching organization.

CURRICULUM ORGANIZATION AND SEQUENCE

1. *Does the teaching of science within the context of team teaching require a reorganization of the traditional "content-topic" oriented curriculum?*

It has been our experience that the pattern of team teaching cannot find its most effective expression unless the curriculum utilized is modified or reorganized in the light of the unique aspects of flexibility which are afforded by this personnel structure. The following aspects seem especially worthy of mention:

1. The possibility of utilizing groups of different sizes, from large groups where two hundred children are taught by one teacher to small discussion, laboratory, and project groups where an almost one-to-one tutorial type of instruction can be offered.
2. The associated possibility of deploying and redeploying a number of teachers according to the nature and size of the pupil groups formed.

Given the two preceding attributes inherent in the team teaching model, the limitations imposed upon the experimental and discovery approaches in the self-contained classroom because of lack of adequate supervision need no longer comprise obstacles to an exciting and creative science program for elementary school children.

The preparation and presentation of extremely worthwhile demonstrations and experiments is now economically feasible time-wise, since not only will the senior teacher in science be allotted adequate time to prepare such presentations, but also since it will be necessary to offer these presentations only once—via the medium of the large group lesson. The structure, wherein many teachers must plan together to develop a science curriculum, also necessitates that the “incidental science” curriculum so typical of many elementary school classrooms be replaced to a large extent by a *planned* and *sequential program* of science experiences. Perhaps, the team teaching pattern will provide conditions conducive to releasing the elementary school’s current preoccupation with the “products and things” of science and raising to its proper position of emphasis, and to a more appropriate balance with the former, the consideration and practice of the “process” of science and “sciencing.”

2. How can the coordination of the science curriculum of an entire teaching team be reconciled with the flexibility of instruction necessary for individual groups?

The team teaching structure provides opportunities for the following: the utilization of large group instruction, the periodic regrouping of students as the situation and their own individual needs indicate, the deployment and redeployment of teaching staff as necessary, the administration of cooperatively developed, team-wide instruments of evaluation, and many more important adjuncts to the learning process. If, however, the flexibility of team teaching is to be utilized to a maximum degree, it then becomes imperative that the efforts of every teacher teaching science within the team be coordinated to a considerable extent. This coordination is further necessitated by scheduling considerations which often require that all science (and this is true for other subjects as well) within a specific team be taught during the same time interval in the course of the school day. This procedure is necessary to facilitate pupil regrouping and the presentation of large group lessons.

However, it is quite important that individual teachers be provided with

the degree of freedom necessary to plan, or modify, within the context of the team's science program, content and activities which are appropriate for the pupils within their own group. Despite the apparent contradiction which the terms may connote, it does seem possible to provide for "coordination" on the one hand, and "flexibility" on the other, without subordinating either one to the other. For example, let us suppose that a particular topic may most suitably be presented through the medium of a large group lesson. It is necessary that the room required for this lesson (for example, the cafetorium) be scheduled in advance because of the program demands for this space which might also be made by the other teams operating within the same building. If it is to be anticipated that most of the pupils in the team are to be present at this large group lesson, it is necessary to agree upon the goals to serve as a foundation for this lesson. If agreement has been reached a week or so in advance of the lesson, it would seem that each individual teacher should attempt to guide her own pupils toward some realistic goal which would provide them with the degree of readiness necessary to make the large group lesson as meaningful as possible. It is certainly quite unrealistic to expect that all children in a team should be approaching the same goal at the same time; however, if given sufficient time and adequate planning, by teachers, it is *not* unreasonable to expect that some commonality of general goal attainment be achieved by a certain time. This requirement places heavy responsibility upon the shoulders of individual teachers, for they must not only carefully assess the readiness of the students in their own group and devise the most appropriate program to bring them to a certain general level in the curriculum by a certain time, but they must also plan considerably further ahead than they are accustomed to do. For some teachers this may mean carefully selecting key points of content upon which to concentrate exclusively; for other teachers it may mean developing a wide variety of enrichment activities to occupy profitably the time of those students who have completed the essential core of science material to be studied by each group.

3. What is the proper place of teaching machines and other programmed materials in science instruction within the team teaching structure?

Within most classrooms utilization of teaching machines and other programmed materials (such as programmed textbooks) has considerable promise for providing greater opportunities for individualizing instruction in the various subject matter areas. The evidence available in the literature suggests that programmed instruction can be used to good advantage for certain specific learning tasks. If we accept the fact (upon which much additional research must be done in relation to the specific applications of this technique) that programmed instruction supplies another possible approach to learning by children, while also providing for greater economy of time in learning—both in regard to actual classroom time

required and to the assignment of professional teaching personnel, then it would seem that for specific purposes this economy would find maximum expression and realization in the large groups possible within the structure of team teaching. Most likely, what can be taught by programmed materials in a group of thirty children could be taught just as effectively in a group of two hundred children.

In the field of science, programmed materials might be utilized for purposes of review and evaluation, drill and practice, and for learning subject matter which required rote memorization (such as science vocabulary words or formulas) or the learning of the steps in the tight logical development of a concept or of the procedures involved in a technological process (such as the extraction of various metals from their ores). However, before we plunge into programming various aspects of elementary school science, it is necessary that serious consideration be given to specifying those behaviors which we expect pupils to acquire as a result of utilizing our programs.

It should be stressed, however, that the possible contribution of programmed instruction to science teaching is only one complementing the contributions of a myriad of other approaches. It is the feeling of the authors that this approach may be somewhat limited in its application. This is especially true if the current philosophies of elementary school science education, based upon providing opportunities for children to seek answers about natural phenomena by having actual manipulative experiences with these same phenomena, are not to be lost.

4. What implications does team teaching have for the development and utilization of various teaching "technologies"?

It is to be hoped that serious thought related to the goals of elementary school science education and to the concepts which we wish to develop will improve the various teaching "technologies" which have been traditionally used in the small group of the self-contained classroom. It is also hoped that new and appropriate instructional aids will be developed. However, the possibility of large group instruction which is afforded by team teaching makes it imperative that considerable effort be expended in transforming the instructional aids designed for use in the small classroom to a form which will be appropriate for their utilization in a very large group. Two criteria, at least, must be satisfied for materials which are to be used with large groups:

1. The materials must be easily seen from all locations in the room where the lesson is to be held; where large rooms and very large numbers of children are involved, the materials—models, projected images, and so on—must be LARGE. We have experienced considerable success utilizing the overhead projector as a "chalkboard substitute" as a light source for a shadow-graph effect, for projecting the images of various semitransparent, translucent and opaque objects

(such as marbles, iron filings, colored solutions in Petri dishes, etc.), and for projecting both commercially-made and teacher-made multi-overlay transparencies.

2. The materials should possess certain "dynamic and dramatic" qualities such as moving parts, unexpected behavior and appropriate contrasting coloration.

Many more qualities have been shown through experience to be necessary ingredients but lack of space prohibits their mention here.

5. What is the proper place of the science textbook within the team teaching model?

As has been intimated in preceding sections, team teaching allows for an unprecedented flexibility and wealth of different science activities. These, in turn, should obviate the former reliance which has been placed in the elementary school science curriculum on the information-dispensing properties of one or two commercial textbooks or trade books. Within the model proposed above, teachers qualified to teach science will be available for the purpose of guiding learning in the area of science as will be sufficient professional staff to supervise experimentation and other activities by students. It is hoped that the textbook in this situation will assume its proper function as another adjunct to learning and will not continue to be the sole dispenser of information about science so common in too many elementary school classrooms. Within team teaching it is possible for the textbook to find its proper niche as a resource or reference to which the children should have ample opportunity to turn when their own investigations or classroom discussions indicate that specific or general information available from this source is necessary.

GROUPING FOR INSTRUCTION IN SCIENCE

1. If greater flexibility in inter-class and intra-class grouping is one of the main attributes of team teaching, what rationale, criteria, or predictors should be utilized to determine the formation of groups of appropriate composition and size for various diverse purposes?

In approaching this question, we should explore the possibility that certain subject matter, and the activities suitable for the presentation of such subject matter, indicate the means by which the total team should be broken down to form the most appropriate "instructional units." For example, does Subject Matter A (e.g., the study of heat phenomena) with appropriate Activities A' (e.g., the laboratory investigation of the expansion of different solids, liquids, and gases) indicate that the team be broken down into small sub-groups of approximate Size X (e.g., manipulative ability)? (e.g., 3 to 4 children per sub-group on the basis of criterion M). Or perhaps, the grouping criterion might more suitably be

I.Q., manifested pupil interest, reading ability, or previous knowledge of the area being studied.

We might also ask the question whether small groups which are homogeneous with respect to a specific criterion are more suitable for certain activities than are small groups of heterogeneous composition which have been formed purely for the advantages accruing from their small size. So far our experience has not provided us with any criterion which we have found highly successful for grouping in science, although we have tried random heterogeneous groups and groups whose composition has been determined by the results of an experimental science vocabulary test which was administered to all the children in one team late last fall.

2. What factors should govern the time and method of regrouping for instruction in science?

This problem is related to the preceding one. It is obvious that usable criteria must also be found for regrouping as well as for the initial formation of instructional sub-groups. These criteria might very well be the same. One generalization which has arisen from our experience is that the composition and size of initially established groups must be flexible and that appropriate regrouping should occur periodically according to the needs of the teaching-learning situation and of the students themselves. Perhaps, regrouping may be accomplished by merely transferring a single child from one group to a more appropriate one after evaluation of the total situation by the teachers concerned. On the other hand, it may be discovered that the underlying rationale for the initial organization of the various science groups of a team has been faulty; in this case, an over-all reorganization of all of the instructional units of the team may be necessary.

3. For what purposes and to what ends can large group instruction best be utilized?

In viewing the optimum utilization of large group instruction, a wide variety of possibilities confronts us. For example, can large group instruction (involving groups of approximately two hundred pupils) best be utilized for the purpose of (1) introducing a unit of study, (2) motivating pupils toward the study of a specific sub-topic of a unit, (3) presenting a teacher or pupil demonstration, (4) hearing a guest lecturer, (5) viewing a particularly outstanding visual aid, (6) raising additional problems for consideration, (7) clarifying a particularly difficult concept which most of the teachers of the team cannot explain adequately, or (8) summarizing a unit or sub-unit at the end of a topic? Perhaps, it is possible that one type of unit, for example, one in astronomy and space travel, might be completely or almost entirely taught in large groups, whereas this approach would not be appropriate for the study of a unit dealing

with rocks and minerals. Perhaps (and we do not have experimental evidence to refute this contention) it is possible that *most* science at certain grade levels (for example, the intermediate level) may be taught in large groups of approximately sixty pupils per group regardless of the subject matter being considered.

Another question which must be considered under this sub-problem is whether large group instruction in science is more appropriate and applicable to certain ability levels than to others. Perhaps the bright, independent child will be stimulated by the presentation of subject matter in large groups and by the relative individual freedom accruing to him from the nature of the group size, whereas the slower child, needing both to receive considerable individual attention from the teacher and to proceed through the curriculum at a slower pace, will not be able to progress as rapidly with this method of instruction as he might in a smaller instructional unit. As a matter of fact, subjective evaluation by one of the authors seems to have confirmed the statement of the situation presented in the preceding sentence: The slower children become very restless in large group lessons and do not seem to derive much benefit from what does occur within these groups. In discussion groups immediately following the large group lessons, these children are often unable to recall even the general nature of what has occurred during the preceding period.

We must also ask ourselves, and obtain an answer to, the following important question: "Where do the great majority of school children—those who fall within the range of 'average' academic ability—fare better (for a particular objective), in the large group or in a group of smaller numerical size?"

It is also necessary to ask how large group instruction may most profitably be articulated with the total instruction pattern which has been established for science. How should children in the various individual science classrooms be prepared for a large group lesson? How should the content of a large group lesson be followed up? Should all children attend every large group lesson regardless of their needs, abilities, and interests? Several points have become increasingly evident during the course of our experience with team teaching: (1) Large group lessons must be planned well in advance. This is necessary so that the teacher presenting the lessons can either meet with, or distribute a summary sheet to, the other teachers in the team so that they, in turn, are aware of and can prepare their students for the content to be considered therein. (2) In many instances, if follow-up of the large group lesson is advisable or imperative, the teachers who are to lead subsequent small discussion or laboratory groups must take the responsibility either to attend the large group lesson themselves or to discuss the lesson with the teacher who presented it. Too often the maximum effectiveness of stimulating and provocative large group lessons has been lost because the other teachers who teach science did not know what had transpired during the lesson and, therefore, could

not develop appropriate follow-up experiences. (3) It has become quite obvious that a single large group lesson cannot be all things for all children. The bright children may have already discussed and mastered the material considered. The slower children may not be ready to consider the concepts being developed or may not be capable of understanding what is being presented at the level at which it is being presented. A possible alternative to requiring all children in all groups to attend a certain large group lesson would be to provide one-to-several "splinter" groups for example, one for the bright children for whom the lesson would be just a review and another for the slower children who would not benefit greatly because of their current lack of readiness. Teachers "released" by the teaching of the large group could be assigned to these splinter groups, where activities more appropriate to the needs and interests of certain children could be offered.

UTILIZATION OF TEACHING MEMBERS OF THE TEAM

1. Under what patterns of teacher deployment and redeployment within the team teaching model can the objectives of science instruction best be served?

There are many questions which relate to the many possible ways in which teachers might be deployed and redeployed to yield optimum learning conditions in science. Careful consideration and research might be directed to the following questions: (1) Can one teacher successfully teach a total group lesson to sixty youngsters at one time? If so, for what purposes and under what circumstances? (2) What criteria might be utilized to enable us to select the most appropriate teacher for a particular group of children? (3) For certain activities, can the flexibility provided by the team organization be utilized to good advantage? For example, if laboratory or individual project work requiring close supervision is indicated at a particular point in a unit of study, would it be possible and appropriate to break a group of sixty children down into smaller units, each supervised by a separate teacher who, for that particular class and activity, has been especially redeployed to this classroom? The students of the redeployed teachers might in turn, be regrouped and assigned to one teacher who would supervise a lesson of programmed study.

For the most part, in the school where we have worked, one teacher has been assigned to twenty-five or thirty pupils for laboratory and discussion sessions. For most teachers, this method of assignment has not proved very satisfactory. Although considerable use has been made of the intra-class "buzz group" discussion technique, adequate supervision has still been lacking for an active experiment and project oriented science program. Collaborative teaching by two and three teachers with groups of thirty to sixty has proved much more successful. The added supervision

made available by this technique has provided opportunities for extensive and intensive laboratory work and teacher-guidance involving a great majority of the children in the groups concerned.

2. How can time be made available to the senior teacher science specialist of the team so that he has an opportunity to discharge the functions inherent in his role?

If, according to the model presented above, the team's specialist in science is to have responsibilities related to the initiation, development, coordination, evaluation, and supervision of the program in science, he must have time during which to perform these functions. It was mentioned in the first part of this paper that the specialist should be released from the responsibility of teaching at least one subject matter area. Thus, some time is made available in the course of the school day for the discharging of his responsibilities related to science. However, it also seems necessary to release the science specialist from the teaching of a regularly scheduled science class at times so that he may observe the other members of the team teach science, so that he may participate in collaborative teaching with various of the team members, and so that he may provide special guidance, supervision, and instruction for special pupil groups (for example, those working on a special project, those setting up a school science display, etc.). Some serious thought must then be given to appropriate scheduling to permit this flexibility. Only two alternatives were utilized this past year in regard to this problem: (1) One of the authors assumed responsibility for the specialist's class several times while he was engaged in classroom visitations with the team; and (2) the members of the specialist's science class were divided equally among the other five science classes for the period. This latter approach has not proved to be desirable or effective for several reasons; especially contributory to this outcome is the fact that very intelligent, highly verbal students were necessarily placed in classes consisting of considerably less gifted students.

EVALUATION

It is evident that the problem of adequate evaluation is not unique or peculiar to the team teaching pattern. However, the entire process of evaluation, especially certain mechanical aspects, is made considerably more difficult because it must be developed in a situation where a number of teachers must work together cooperatively to determine what approaches are to be utilized. The following questions, then, which are undoubtedly applicable to many types of personnel organization found in the elementary school, are especially pertinent to the team teaching structure.

1. *What should be the main emphasis in the evaluation of science instruction within the team teaching model?*

We have mentioned in an earlier section of this article that it is rather unrealistic to expect all of the children in a team to have acquired a certain amount of science knowledge or to have attained a certain level of science sophistication by a certain point in time. Within the team structure, where individual science groups may be proceeding through only limited portions of the science curriculum via different methods of approach, is it educationally desirable for us to evaluate all youngsters by a method which assumes that they have considered the same subject matter in the same way? Perhaps not. Let us only say at this point that it is very necessary for us to review the major goals for which we are teaching science in the elementary school and then to determine the outcomes which we wish to have assessed by our instruments of evaluation. In any case, an understanding of the process or methods of science should undoubtedly serve as a more prominent target for evaluation than in the past, while the current emphasis solely on retention of scientific fact should be moderated accordingly.

2. *What are some of the characteristics of an adequate testing program in science within the structure of team teaching?*

The characteristics of an adequate testing program in science within the model proposed above should not be very much unlike those of an adequate testing program in any good elementary school, regardless of the personnel structure. There are many obstacles standing in the way of good testing programs in elementary school science, in general. The most important and significant of these obstacles is serious lack of availability of a variety of different kinds of standardized tests for the various elementary grades. A survey of current elementary school science tests does not provide a very impressive list of up-to-date and carefully devised instruments designed to evaluate the child's science interests, his understanding of science as a process, the nature of the scientific enterprise and of the scientists, and his factual knowledge in various specific content areas. Some adequate tests designed to evaluate the scientific reasoning of children are available, however. It is evident that appropriate tests designed to evaluate the areas mentioned immediately above are urgently needed.

It is also important for teachers within the team pattern, as well as elsewhere, to learn to devise effective teacher-made tests. Generally, the science test questions asked by many elementary school teachers of their students are of a purely factual nature or are worded in an exceedingly ambiguous and frustrating (for the children) manner.

Perhaps within the team structure, where several teachers might be deployed to a single classroom, evaluation procedures other than those utilizing paper and pencil tests might be employed. For example, the

responses of individuals or of small groups of children to an original problem depending for its solution upon an experimental approach might provide carefully observing teachers with important information of an evaluative nature.

3. How might evaluation procedures best be developed within the team structure?

As has been mentioned, evaluation, within the team structure, of both the students involved and of the total effectiveness of the science program, is a cooperative and collaborative endeavor. Although individual teachers might find it desirable at times to develop evaluation instruments for use within their own classes, valuable ideas are to be gained by consultation with the science specialist and with fellow team-mates. Unit-end and year-end evaluation of all the students in a team necessitates the cooperation of all those teachers involved in teaching science within the team. The experience of the teachers of individual science classes must be pooled in order to develop an instrument which will be as valid as possible for all children of the team. A paper and pencil test might consist of a series of "difficulty ranked" items some of which could be answered by the members of even the "lowest" science group. The group of items as a whole should represent, in an equitable fashion, all of the major goals and objectives for which science is being taught. In any case, it has been found fairly effective to ask individual teachers to submit a series of questions which they would consider appropriate for their own class to a sub-team assigned to construct the evaluation instrument. These questions are then "hashed over" and refined in subsequent meetings of the sub-team. The questions are then resubmitted to all the teachers involved in teaching science within the team. After a final discussion and revision of all of the items by the former group, the finished instrument is then produced by the sub-team.

Periodic and end-of-the-school-year evaluations of the total science program of a team should incorporate the efforts of all team members. These evaluations might consider the appropriateness and effectiveness of content, methods utilized, staff utilization, and pupil evaluation. It seems that only in this way can a science program be restructured and developed in a direction which is consistent with both the philosophies of the majority of the team members and with the facts gleaned from the evaluation instruments administered. Hopefully, a cooperative evaluation program of this nature will eventuate in the provision of better conditions for learning and more appropriate and stimulating experiences in the area of science instruction.

TELEVISION IN SCIENCE EDUCATION*

National Center for School and College Television

This article is a report on a conference on television and science education held by the National Center for School and College Television (NC SCT). Eleven representatives from universities, state departments of education, public school systems, federal government agencies, and educational television stations met with NC SCT staff members. The purpose of the conference was to assess television materials now being offered in science. Presented is a status report of science telecourses being offered in the United States during the school year 1966-1967 and an overview of the discussion among the persons who participated in the conference.

This report concerns the conference of the National Center for School and College Television (NC SCT) on television in science education. Members of the following eleven institutions met with NC SCT staff members at the conference: University of Wisconsin, Ball State University, Florida State University, Georgia State Department of Education, Hawaii State Department of Education, Los Angeles County School System, Portland (Oregon) School System, National Science Foundation, American Association for the Advancement of Science, National Aeronautics and Space Administration, and Educational Television Station WQED.

The conference was conducted to assess television materials now being offered in science in an effort to stimulate the development of increasingly effective television materials for the nation's schools. The eleven conferees viewed sample lessons from telecourses, reviewed print materials, teacher's manuals and student work materials, and, during the final session, considered the state of television in science education.

PART I—THE STATUS OF TELEVISION IN SCIENCE EDUCATION

For this conference, questionnaires were sent to 116 educational television stations and two closed-circuit facilities. Information resulting from those questionnaires is the basis for this section of the report. This report does not consider materials developed or offered by commercial television stations. It is concerned with materials used only in classroom instruction.

Seventy-nine different telecourses were found in use at the elementary

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and secondary levels. One program was designed for use at the elementary grade level.

Elementary Grade Level

GRADE EMPHASIS. The division according to grades revealed a heavy but anticipated emphasis on materials designed for elementary education. Eighty-two per cent of the telecourses (66 courses) was designed for use at the elementary grade level.

Seventy-three per cent (47 courses) was intended for the intermediate grades (grades four through six) while 27 per cent (19 courses) was intended for the primary grades (K through three).

FREQUENCY OF TRANSMISSION. Of the sixty-six elementary grade level telecourses, 73 per cent was designed to be used throughout an entire academic year, and 27 per cent was intended for use for a single semester.

Of the sixty-six telecourses, 40 had a transmission rate of one lesson each week, 22 telecourses had a rate of two lessons each week, and four telecourses had a rate of three lessons each week.

RECORDED OR UNRECORDED. Almost 90 per cent of the telecourses at the elementary grade level was recorded and available for later use.

USED BY OTHERS. Less than one-third of the telecourses was used by stations other than the producing station.

Secondary Grade Level

GRADE EMPHASIS. Thirteen telecourses were designed for the secondary grade level. This was 17 per cent of the total number of telecourses.

FREQUENCY OF TRANSMISSION. Of the 13 secondary grade level telecourses, nearly 77 per cent was designed for use for a complete academic year, and 23 per cent was designed for one semester.

Five of the 13 telecourses had a transmission rate of one lesson each week, three telecourses had a rate of two lessons each week, a single telecourse had the rate of three lessons each week, and four telecourses had a rate of four lessons each week.

RECORDED OR UNRECORDED. Eleven telecourses were recorded and available for later use.

USED BY OTHERS. Six of the telecourses were used by stations other than the producing station.

In-Service Teacher Education

Only one 30-minute program was designed for in-service teacher education.

PART II—AN OVERVIEW OF THE DISCUSSION OF THE CONFEREES

NCSCT is conducting additional meetings with science and television authorities as a result of its first assessment of television in science education. The science authorities, convinced of television's potential in science education, urged additional conferences to permit further analysis, the development of standards for television production, and the development of review and testing methods for materials based on those standards.

The 11 authorities explored the current status of televised science lessons for elementary and secondary schools. At the conference they viewed and discussed portions of 80 lessons, representing the output of most of the educational television stations in the country. They were able to review enough of each lesson to permit valid judgments.

Among the subjects considered were the quality of the television teaching, the science content of the lessons, the validity of television as an instructional medium in science education, the objectives of televised science lessons, and the usefulness of related materials such as teachers' guides. Comparisons were made between the functions of the television teacher and those of the classroom teacher.

While there was not complete agreement among the conferees on all points considered, several generalizations and questions concerning the overall use of television in science teaching were formulated. These are here reported.

There was agreement that improvements are needed in all phases of school television in science education.

USE OF THE MEDIUM. Four major functions of televised science lessons were identified. Some telecourses apparently are intended as the sole instruction available. In a larger number of instances televised lessons represent the major portion of the science program. These lessons are intended to receive support from a classroom teacher in the form of introductory lessons, summary lessons, drill, and testing. A third kind of situation involves the use of television as a minor contributor to the instructional program which, in turn, is accompanied by other instructional activities and media. Still a fourth use is the influence the television lesson's content and method has on the classroom teacher. In one instance the in-service education of the teacher was the explicit aim. In most other instances possibilities for the television lesson to affect the classroom teacher in terms of his subject matter competency, his attitudes toward science teaching, and his teaching techniques were obvious. These influences caused considerable speculation among the conference participants.

The effectiveness with which televised science lessons can serve these functions must be explored. In spite of the use of television for

instructional purposes there still remains a great need for classroom teachers who are well prepared in terms of subject matter and teaching ability. On the other hand, the television teacher tends to assume a significant place in the science program and his influence cannot be ignored.

QUALITY OF TELEVISION TEACHING. The role and influence of the television teacher is not fully understood at present and should be the subject of further research. The conferees identified two attributes of a good television teacher:

1. He must have the ability to develop some form of rapport with his audience and to be skillful in communicating with his unseen pupils.
2. He must have an excellent understanding of his subject matter. These qualities, of course, are related.

It appears that the quality of the teaching in a majority of the television lessons is not superior to that in many classrooms. Very likely increased attention must be given to the selection and training of television teachers. Perhaps there is a need also for supervision of the television teacher in terms of the validity of the subject matter, the organization of the lesson, the use of scientific apparatus, and the use of appropriate teaching procedures.

Throughout the discussions at the conference it was difficult for the participants to separate in their thinking the performances of the television and classroom teachers. The following comment was typical. "Regardless of what we want television to contribute, the television teacher becomes a model for all other teachers; if he stresses verbal learning the classroom teacher will do likewise."

Few generalizations concerning classroom and television teachers were possible because of the great variation in the quality of teaching. Some television teachers are better than some classroom teachers and vice versa. Attempts to make this comparison are complicated by the fact that these two teachers are not always trying to do the same thing. The criteria for judging who is "better" are not clear at present. The fact that these comparisons were attempted probably illustrates the conferees' uncertainty concerning the roles of these two persons.

The prominence of the television teacher in the lessons was questioned by some who thought that perhaps the content should be more dominant than the teacher. On the other hand the personality of the television teacher may have an important influence on learning, a fact which is not fully understood or exploited at present. Since the televised science lesson is usually employed as part of a larger instructional program carried on within the school, the classroom teacher and the situation within which he operates should be the subject of research.

In the lessons that were viewed one or two attempts were made to involve the pupils as more than passive receptors of information. In one lesson the television teacher provided a three-minute break during which the pupils were to discuss the points made earlier. Other possibilities for stimulating pupil involvement emerged during the discussions. Among these was the suggestion that the television lesson be so structured that the classroom teacher could turn it off when the students had reached a desirable level of readiness for work on their own. It was also thought that the television teacher could suggest pupil activities to be performed in the classroom or at home.

CONTENTS OF THE LESSONS. In many lessons there were subject matter errors which could have been corrected had the lessons been viewed by subject matter specialists. Two types of errors occurred, both common to television and classroom instructor. Errors committed in televised lessons, however, are perhaps more serious because of the size of the viewing audience. One type of error occurs when the teacher is trying to simplify in order to adapt material to the level of pupil maturity. The problem of reducing the frequency of this type of error will be solved only after curriculum workers have a greater understanding of the ways in which children conceptualize natural phenomena. To what extent can an adult topic be simplified without destroying its validity at the pupils' level of understanding? The second type of error results simply from the teacher's misunderstanding of the subject. These errors can be reduced by improvements in the education and selection of teachers and the use of science curriculum consultants during the production of television lessons.

The appropriateness of much of the content for presentation by means of television can also be questioned. In many of the lessons the content was not selected on the basis of the unique qualities of the television medium. Much of what was viewed could just as well have been taught by classroom teachers. This leads to the question of exactly what the role or roles of school television should be.

VALIDITY OF TELEVISION AS AN INSTRUCTIONAL MEDIUM.

The 80 television lessons left the participants in the conference with a strong impression that the role of school television in science education needs to be clarified. There is a need to define what aspects of the science program should be dealt with by means of television.

Who should determine the science curriculum for a particular class? Several participants expressed the point of view that the classroom teacher should be the one to select the specific content to be taught and the learning activities to be employed in the classroom and that telecasts should be employed along with other media.

"The content has to be supplied by some route and television can be one of these routes," said one conferee.

The effectiveness of a televised lesson depends not only on its subject

matter but also on the ways in which the videotape is used in the classroom. To aid the teacher, guides are needed that show the relationship of the lesson to the total science unit and course. Guides should also contain suggestions for introductory and follow-up lessons. Many of the guides accompanying the sample lessons studied during the conference could have been improved.

One of the unique features of television is the rigid schedule of the broadcasts which requires that children in all participating schools view a given lesson at the same time. Some conferees regarded this as a "straight jacket" that inhibits the flexibility of the program in individual schools. Others defended it in terms of the stimulus it provides for all schools to keep from lagging in their treatment of the subject. To overcome this attribute of televised lessons that are broadcast some proposed that a "systems approach" be developed in which videotaped lessons or portions of lessons would be accessible to classroom teachers over closed-circuit systems at the push of a button.

OBJECTIVES OF TELEVISION INSTRUCTION. Participants in the conference were encouraged to suggest and explore other innovations in the use of television in science education. At one point they were asked, "If we could remake science instruction, what role would you like to see television playing in the near future with the use of the present technology?" Among the responses were the following:

1. Television should be used for the in-service education of teachers in terms of both subject matter and instructional methods. Lessons might be used to describe and to show ways of implementing the materials produced by recent science curriculum projects.
2. Emphasis should be placed on the use of television to aid the classroom teacher and not to replace him. Lessons should be designed to come at a variety of places in a science unit and to be more peripheral than central, so that the predetermined broadcast schedule would not set an unrealistic pace for many schools. Televised lessons that supplement the science unit by raising questions, showing applications of principles, and bringing in relevant current events are of the type that could serve this function.
3. Televised lessons should be subject to continual revision and innovation. The medium's flexibility should be exploited to keep the televised materials up to date, free from error, and as relevant to the courses of study as possible.
4. Television can serve a public relations function for the schools. Parents should be encouraged to view the broadcast and learn from them ways in which they can work with their children in science. Good public relations can also be achieved by means of telecasts describing the schools' science program and objectives.

CONCLUSIONS. The major accomplishments of the conference were the general exploration of the status of the art, the identification of problems, and the exploration of issues. "Need research" was a recurrent theme in the discussions. Television in education is apparently here to stay. At present it has many faults and unrecognized potential which need to be explored. Teachers are using television and we have to find out how and why. Above all, the question of how television ought to be used remains unanswered. This exploratory conference is being followed by another NCSCT-sponsored conference in which school television in science education will be more thoroughly analyzed and standards for the development of televised lessons will be suggested.

CHALLENGING THE MORE ABLE STUDENT*

Theodore W. Munch

Every classroom has its share of exceptional children. Meeting the needs of all of these students presents many organizational and planning problems to the classroom teacher. Theodore W. Munch presents one way of challenging the more able student—namely, the use of simple unstructured experiments. Six specific scientific skills should come into play as the more able child works through the unstructured experiment. Dr. Munch describes a recent unstructured experiment that evolved in a sixth grade class.

One way of challenging the more able student in your classroom is to help him work through a simple, unstructured experiment. Essentially, an unstructured experiment is a question or a statement of a problem, the answer to which cannot be found in a text or an encyclopedia—at least not easily so. Unstructured experiments differ from the average science experience in that the former do not have a fixed number of things to do, and the results cannot be determined in advance. Such experiments are research in the true sense of the word, not cookbook type experiences.

* REPRINTED FROM *Elementary School Science Bulletin*, Issue No. 74, December 1962, pp. 1-3. Copyright, 1962, by the National Science Teachers Association, Washington, D.C. Reprinted by permission of the author and the publisher. Dr. Munch is Professor of Education and Physics at Arizona State University, Tempe.

Working on unstructured experiments involves a number of skills:

1. Isolating and defining problems concisely.
2. Discovering what other people (scientists, engineers, and technicians) know about the problem. This involves reading, talking to, and sometimes writing to people to obtain information. Reading often contributes ideas about how to approach experiments.
3. Hypothesizing, that is, getting ideas about possible solutions to the problem.
4. Assembling equipment or inventing simple apparatus to test hypothesis.
5. Collecting and recording facts discovered while testing hypotheses.
6. Drawing conclusions from the facts and information he has gathered.

Doing unstructured experimentation is not as involved as the description would imply, and children find it stimulating. Here is a recent unstructured experiment which evolved in a local sixth grade class.

In a study of chemistry, the class learned about acids and bases. They found that acids taste sour, and that bases were often bitter and slippery to the touch. They also learned that acids and bases could be harmful to the human body. In the course of their work they discovered that there was a safe way of telling whether things were an acid or base. (This is done by using certain chemicals which chemists call indicators.) These are substances which have one color in acids and another in bases. The teacher obtained some red and blue litmus paper from a high school chemistry teacher. The class found that in acids, blue litmus turned red; and in bases, red litmus turned blue. The supply of litmus paper was limited, so the teacher wondered aloud if other substances found about the home could be used as indicators. He wondered particularly about the juice from red cabbage. Several volunteers brought some cabbage juice to class the next day. The juice was made by boiling cabbage and filtering the water through a paper towel placed in a funnel. Cabbage juice was found to turn red in acids and bright green in bases.

INDICATORS

The first unstructured experiment suggested itself: "What plant extracts make good indicators?" In less than a week, the class had extracted and tested the coloring from twelve different flowers and several vegetables. Red cabbage juice still seemed to be the best indicator. During the week, the students discovered through reading and class work the meaning of pH (a way of measuring the amount of "acidness" or "baseness" of solutions). They also discovered that acids and bases could neutralize each other to form a salt and water, and that certain indicators would react only within a narrow acid or base range.

The teacher suggested another unstructured experiment that the class could carry out now that there was a good indicator at hand, "Which common household things are acid and which are base?" The students made solutions in distilled water of aspirin, vitamins, seasonings, and many other items brought from home. Each was tested using the cabbage juice as the indicator. Each item was carefully classified under the heading of "acid," "base," or "neutral," as tested with red cabbage juice.

Here are some additional ideas which can be used as points of departure for simple, unstructured experimentation.

How does light, filtered through various colors of cellophane, affect the growth of plants?

Is dry yeast or wet yeast best for baking bread?

Is there any relationship between the number of turns of wire on an electromagnet and the number of tacks the magnet will attract?

How much weight will sprouting bean seeds lift?

While conducting your unstructured experimentation, here are some points to keep in mind:

Start by using the combined talents of the class or group. Later, when routines are established, individuals may explore on their own.

Keep the experimentation within the limits of time, talents, and easily available apparatus. Explore these limitations *before* suggesting problems.

Be alert to the open-endedness of this type of experimentation. Frequently, questions will arise such as "Suppose we varied the experiment in *this* way, what will happen?"

Do not assume that even the gifted child will continue to have a sustained interest in a problem. You must continually check on progress.

A second method of challenging the more able learner in science is to include as many quantitative aspects as possible into the units. In addition to answering "how" or "what," help the child to find out "how much" or "what relationships exist between?" Being quantitative involves combining mathematics with science. Let us explore a problem in which the quantitative aspects are stressed.

Have the children plant 15 grass seeds in each of four different flower pots, all having identical soil. Cover the grass seed with a different color cellophane, red, yellow, or blue. Keep one pot in sunlight as a control. Allow the grass to grow for two—three weeks. Now have the students measure the height of each blade of grass to the nearest millimeter (or to the nearest $1/16$ of an inch). This would be an excellent opportunity to compare the metric and English system of measuring length. Have several students measure each blade of grass and determine an average height for their particular pot. This is done to help eliminate individual errors of

measurement. Now find the average height for *all* of the blades in that pot by getting a total of all blade measurements and dividing by the number of blades measured. The chart of your data might look like Table 1. (This is imaginary data and will not necessarily resemble data the class gathers.)

TABLE 1
*Heights of Grass Seedlings
Grown Under Blue, Yellow, and Red Cellophane
(All Heights Are in Centimeters)*

<i>Seedling</i>	<i>Blue</i>	<i>Red</i>	<i>Yellow</i>	<i>Colorless (Control)</i>
1	10.2	11.5	7.3	13.1
2	10.0	11.2	7.2	13.0
3	11.0	12.3	7.5	13.2
4	10.5	12.6	7.7	11.0
5	10.6	10.8	8.0	13.3
6	9.8	10.7	7.1	13.5
7	10.3	11.5	7.0	13.7
8	10.4	11.6	6.5	13.8
9	10.0	11.7	6.3	13.6
10	9.7	12.0	7.4	13.9
11	8.8	10.0	7.7	12.1
12	10.6	11.3	7.8	12.0
13	10.8	11.8	7.9	13.3
14	10.4	11.9	7.6	13.5
15	10.3	11.7	7.3	13.7
Average Height	10.2 cm.	11.5 cm.	7.4 cm.	13.1 cm.

How can you express the facts found in this experiment in a more concise fashion? Here are several suggestions:

Place the average heights in a column:

Yellow	7.4 cm.
Blue	10.2 cm.
Red	11.5 cm.
Colorless (control)	13.1 cm.

By such a simple arrangement, you have brought the data into a neat column which is easier to read and interpret.

Discover and record, in a column, the *range* of heights in each pot. The range is merely the height of the smallest plant and the height of the largest.

*Range of Growth of Grass Seedlings Under
Various Colors of Cellophane*

	<i>Low</i>	<i>High</i>
Yellow	6.3 cm.	8.0 cm.
Blue	8.8 cm.	11.0 cm.
Red	10.0 cm.	12.6 cm.
Colorless (control)	11.0 cm.	13.9 cm.

Notice that with this arrangement, you can tell at a glance which pot had the shortest plants and which had the longest. These ideas will help you decide which color of light most stimulated or retarded growth. If the ranges overlap to a great degree, you cannot say that any particular color of light affects growth more than any other. If the ranges are widely separated, you may suggest that certain colors affect plant growth more than others.

You may also want to assemble data in the form of a bar graph. (Table 2 shows a bar graph of the range of plant heights.)

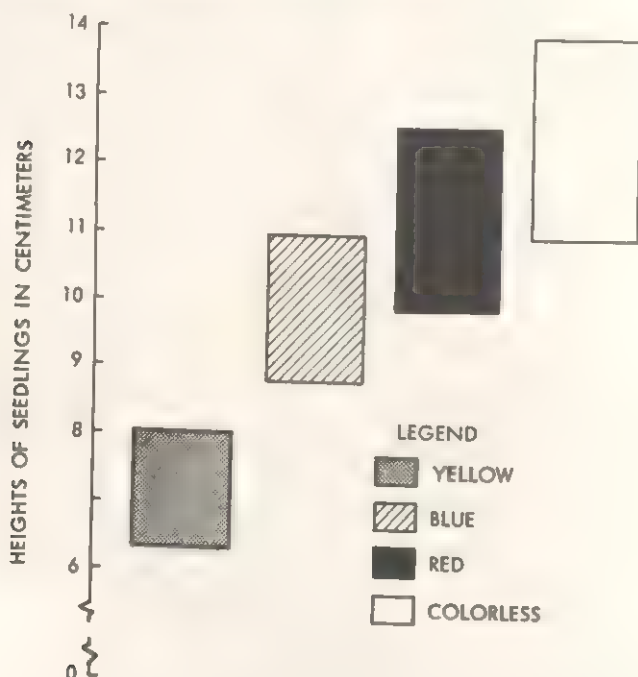


TABLE 2

*Bar Graph Showing Range in Heights of Seedlings
Grown Under Blue, Yellow, Red Cellophane*

By treating your data in this fashion, you have gone far beyond just looking at the grass and "guesstimating" about the effects of light. You have accounted for more subtle differences which may not be noticeable in a cursory, qualitative examination. Most important, you have started the students in the way scientists work at assembling and interpreting the data they receive from experimenting.

THE CULTURALLY DEPRIVED CHILD AND SCIENCE*

Samuel Malkin

The teaching of children who are termed "culturally deprived" is one of the major problems in education today. The past five years have seen a surge of much-needed experimental approaches to the teaching of this exceptional child. Science education can play a great role in assisting these children who generally have extremely limited experiential opportunities. No other area of the curriculum offers quite the same opportunity for meaningful experiences as does the science program. Samuel Malkin discusses how the science program should be used in approaching instruction with this disadvantaged child.

Educators have always had the problem of adapting the curriculum to the needs of children with special problems. Today teachers throughout the country, particularly in urban areas, are being confronted in ever-increasing numbers by the special problem of the culturally deprived or disadvantaged child. In New York City, it is estimated that 225,000 out of 573,000 elementary school children and 75,000 out of 186,000 junior high school pupils are in that category. Coupled with the disadvantaged or culturally deprived child is the non-English speaking child. About 11.5 per cent of the entire elementary school population of New York City speak English haltingly or not at all.¹

* REPRINTED FROM *Science and Children*, Vol. 1, No. 7, April 1964, pp. 5-7. Copyright, 1964, by the National Science Teachers Association, Washington, D.C. Reprinted by permission of the author and the publisher. Dr. Malkin is Supervisor of Audio-Visual Instruction, New York City Board of Education.

¹ *Higher Horizons Progress Report*. Board of Education of the City of New York. January 1963.

What are some characteristics of these children? In working with them, one quickly becomes aware of their general lack of achievement in the basic academic skills of reading, writing, and arithmetic; their general low self-image; and their lack of interest. Then one becomes aware of their limited experiences. What we tend to take for granted in youngsters—that they are familiar with gardens, pets, automobiles, trains, bicycles, elevators, and the country—is not necessarily true for these children. Indeed, many have never strayed from their own neighborhood or block, even though they may live in a city with many places to go and things to do.

What are some of the conditions that cause cultural deprivation? Although poverty may not in itself be a cause, most culturally deprived children come from poor areas. Many come from broken homes or from families with deteriorated social standards; many come from areas where there is conflict between their own existing subculture and the standard American middle-class culture. Then, too, these areas may contain a constantly changing population with families moving in, staying awhile, and moving away again. The youngsters may have no roots, no feelings of loyalty, or no sense of responsibility to the community.

Teachers need orientation to work with these children since the children's expectations contrast sharply with the teaching and therapeutic processes which the teacher is normally trained to use. For example, these children desire authority and direction rather than training in self-direction; they desire action rather than introspection; they desire structure and organization rather than a permissive situation; they desire simple, more concrete, scientifically demonstrable explanations rather than symbolic, circuitous interpretations; and they desire informal, sympathetic, nonpatronizing relationships rather than intensive ones.²

These desires and expectations of the disadvantaged child are positive elements upon which a functional and developmental curriculum can be built. Frank Riessman, in his book *The Culturally Deprived Child*,³ strongly advocates such an approach. His observations identify other elements which have a direct bearing on the development of curriculum for these children. These are: ability in abstract thinking, but at a slower rate than middle-class children; skill in nonverbal communication; greater achievement when tasks are motor-oriented; and greater motivation to tasks which have tangible and immediate goals.

An elementary science program for such children must be based on the positive elements of the characteristics, environment, and expectations of these children.

² Frank Riessman, *Some Suggestions Concerning Psychotherapy with Blue Collar Patients*. Mobilization for Youth and Department of Psychiatry, Columbia University, New York City. Unpublished Mimeographed Paper. 1963. p. 4.

³ Frank Riessman, *The Culturally Deprived Child*, Harper and Row, New York City. 1962.

WHAT ARE THE FEATURES OF SUCH A PROGRAM?

An elementary science program must be based on the pupils' environment.

Children are concerned with the world about them; the sound of bells, thunder and lightning, automobiles, airplanes, trees, birds, and their own bodies. Disadvantaged children are no exception; however, their own world may not be the same as their teacher's world. To the teacher, larva, pupa, and butterfly are part of nature; to the pupils these may be meaningless because they may never have seen these things. Skyscrapers, concrete, and alley cats are more meaningful to these children than the Grand Canyon, sedimentary rocks, and protozoa. The culturally deprived child's environment is quite restricted, and we must seek from his environment those elements familiar to him and build our program upon them.

It is also important to enlarge the pupil's environment. This suggests that he be given direct experiences through audio-visual materials. A trip to the farm or zoo where the urban slum child can see and fondle farm animals, a lesson on magnetism where he and his fellow pupils can handle many different magnets, or a film which shows him what makes night and day are all experiences which will enlarge the pupil's concepts about his environment.

AN ELEMENTARY SCIENCE PROGRAM MUST BE BASED ON REAL PROBLEMS

Children ask questions about their environment and want answers to their questions. Some of these questions are: How does the school bell ring? What makes the light go on? Why do we want to explore outer space? How can we keep food from spoiling? How does the weatherman forecast weather? How does a telephone work? How can my skates roll more easily? What makes a car stop? Whereas many children frequently obtain the correct answers to their questions from parents or from books, the culturally deprived youngsters generally do not. Their parents are not able to help them and they are not able or motivated to help themselves. They must rely on the school for the correct answer, or else be satisfied with misinformation or no answer. The implications are clear. The teacher must gear her program to help these children find answers to questions about their environment. Indeed, the teacher may need to help the children verbalize questions which their environment has led them to submerge. Questions, such as those listed above, could and should serve as the aims of lessons in elementary science. By basing the aims of her lessons on real problems, the teacher can capitalize on pupils' interest and compensate for the learning they should, but do not, receive at home.

ELEMENTARY SCIENCE SHOULD NOT DEPEND ON READING OR OTHER ACADEMIC SKILLS

A major weakness of the disadvantaged child is lack of achievement in reading and other academic skills. This lack of achievement in reading probably accounts, in large measure, for lack of success in other curriculum areas which depend on reading. If an elementary science program is to be successful, then the pupils must feel that they can succeed in science. I conceive of elementary science as a truly "democratic" subject—democratic to the extent that every child can participate in, and get a feeling of, achievement and success from it. Therefore, it is important that activities be so chosen that they do not discourage children. One way to do this is to use children's language skills, other than reading, in the elementary science program. Such skills as listening, speaking, reporting, observing, and note-taking (at the pupil's level) should be encouraged.

Teachers should plan lessons which draw on pupils' experiences, and the conclusions to each lesson should be elicited from the class in the pupils' own language. Audio-visual materials should be used extensively to provide basic information and material for research. Children can use filmstrips with individual viewers just as they would use books. The formation of soil and the operation of the water cycle can be demonstrated more effectively by films than by books.

Although the basic science program should not depend on textbooks, children should have contact with many science books at their own reading level. Thus, instead of 30 books of a basic series of texts on one grade level in a class, it might be possible to have 30 books of many series at different levels. Trade books on many topics at varying reading levels should be available. In this way, children could select those books which they are able to read, and which do not frustrate them.

ELEMENTARY SCIENCE SHOULD REINFORCE BASIC ACADEMIC SKILLS

Although this may seem contrary to what was previously stated, it is not. Elementary science can and should encourage and motivate growth in reading. As these children get a feeling of success from their science activities, they may be motivated to greater achievement. Thus, they can be encouraged to use some of the trade and textbooks that are to be found in the room. Elementary science can provide even more basic reading experiences. Labelling of specimens, models, and charts provide reading experiences, as do captions on filmstrips. In my own experience, at the end of each lesson I ask the children to tell me what they have learned from that lesson. Their own statements are written on large sheets of paper and the pupils copy these in their notebooks. Many weeks later

the pupils are able to read their statements, although they may not be able to read at that level in their basal readers. They are able to read their experience charts because they are motivated to learn to read those statements which arise from their own experience. Elementary science is used to motivate these pupils.

A more formal experiment correlating science and reading is being conducted by Richard Kinney, at Public School No. 188 in Manhattan. In this experiment, reading lessons, based on the children's science experiences, are being prepared on three reading levels. The results so far have been encouraging and point to further study in this area.

ELEMENTARY SCIENCE SHOULD AFFORD CHILDREN OPPORTUNITIES TO HANDLE MATERIALS AND EQUIPMENT

A fundamental concept in teaching elementary science is that all children should have an opportunity to handle materials and equipment. This is especially true for the culturally deprived child since he seems to have greater achievement when tasks are motor-oriented. Teachers, therefore, should provide every opportunity for children to participate in demonstrations and experiments. If possible, there should be enough material so that every child can use the same materials at his seat that his teacher is using at her desk. Kits of materials can be organized which contain, for example, 30 dry cells, 30 switches, 30 bells, and pieces of wire, or 30 sets of different magnets. The materials that are used should be familiar to children. Esoteric and elaborate equipment should be avoided since it may be confusing to children; and assume importance rather than the science concepts being demonstrated. Children should be given recognition for their projects by having their exhibits displayed to other pupils as well as to their parents and to the community at periodic science fairs.

Through proper adaptation of the elementary science curriculum to the needs of this large portion of our children, we may bring about an enrichment of their lives which, in turn, will benefit our entire community. We have, so far, failed to tap America's greatest resources, the creative skills and abilities of all its children. Among these disadvantaged children, there is a large reservoir of future high-level, professional, and skilled personnel, if we learn how to help them realize their potential.

Throughout the country, experimentation with curriculum development for the culturally deprived children, such as the "Higher Horizons Program" and "Mobilization for Youth" in New York City are providing insights into the techniques of teaching such children. Through implementation of our new insights, both society and the child will benefit.

AN ANALYSIS OF RESEARCH RELATED TO INSTRUCTIONAL PROCEDURES IN ELEMENTARY SCHOOL SCIENCE*

Gregor A. Ramsey and Robert W. Howe

The Educational Resources Information Center (ERIC) comprises a network of decentralized clearinghouses in various locations throughout the United States. The ERIC clearinghouse for science education is located at Ohio State University and is designed to help teachers keep informed of new instructional techniques and materials. The following contains that portion of an article which refers specifically to an analysis of recent research related to instructional procedures in elementary science. Eleven research categories, together with an extensive bibliography, are included: (1) Comparative Studies: Traditional vs Nontraditional, (2) Audiovisual Aids, (3) Programed Instruction, (4) Individualized Instruction, (5) Ability Grouping - Socioeconomic Status of Students, (6) Use of Reading Materials, (7) Critical Thinking, (8) Process: Inquiry in Science, (9) Problem Solving, (10) Creativity, and (11) Concept Development.

The purpose of this article is to report to the profession an analysis of recent research related to instructional procedures used to teach elementary school science. The reviewers found it necessary to place arbitrary limits on the studies reviewed so that the field could be contained in manageable form. In general, only studies reported after 1960 were examined, and from these only those studies which attempted some objective evaluation of the outcomes of an instructional sequence are discussed in detail in this article. Likewise, studies which were designed to test various aspects of learning theory, although they may have used a novel instructional procedure to do this, were ignored. Learning theory forms an important basis for designing an instructional procedure, but it has only an indirect effect on classroom teaching.

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The studies are reviewed in terms of whether they focused on the instructional procedure, e.g., inductive or deductive, individualized instruction, programed instruction, or whether the studies focused on outcomes, e.g., development of concepts, attitudes, problem-solving skills, creativity, or understanding content. It was surprising to find the outcome category "development of psychomotor skills" void, since it might be expected that this would be an important area to be developed in elementary school science. No information was obtained concerning what manipulative skills in science can be developed in elementary school children, nor whether a hierarchy of such skills can be identified. This area requires much more basic research.

A number of "status" studies were identified. School systems were surveyed for procedures used, e.g., Snoble (113)¹ and Swan (120), or wider surveys of national practices were made, e.g., those by McCloskey (79), Moorehead (83), Smith and Cooper (111), Blackwood (13), Stokes (116), and Melis (81).

These status studies are in a sense reviews themselves and provide sound statements of the position in the areas mentioned. They are not discussed further in this article, but are cited as useful sources for the interested reader.

Only one study was identified which attempted evaluation of one of the newer course improvement projects in elementary science. This study was undertaken by Walbesser, *et al* (126) and the American Association for the Advancement of Science in their comprehensive study of *Science—A Process Approach*. An evaluation model was posed which described expected learner behaviors and established what might be accepted as evidence of learner accomplishment. Evaluation in these terms allows for objective comparisons of courses, gives objective evidence that learning has occurred, and makes independent replication of the findings possible.

The behavioral objectives of each instructional sequence were clearly identified, and they were evaluated by determining the percentage of pupils acquiring a certain standard percentage of specified behaviors, and comparing this to an established level of expectation. From this information, feedback to improve the instructional sequence was constantly available. For example, an arbitrary 90/90 (90 per cent of students acquire 90 per cent of the prescribed behaviors) was chosen as the standard. If the standard attained by pupils were lower than this, then modifications were made to the instructional sequence.

Specific findings of the evaluation were too varied and far reaching to be described in a review of this nature; however, it is the model provided by the evaluation, rather than the results which are important. Much has been said and written about the efficacy of stating objectives in behavioral terms. This study gives concrete evidence that this is so.

¹ See references.

COMPARATIVE STUDIES: TRADITIONAL VS. NONTRADITIONAL

In this section are reviewed those studies which compared outcomes obtained when the same body of content is taught by two methods. A "conventional" or "traditional" method was the usual standard of comparison, although what researchers meant by these terms was not always clear. Methods investigated included "inductive," "directed self-discovery," a "field method," "democratic," and "problem solving." It was in this area of comparison studies that the reviewers had the most concern regarding the research design. It is extremely difficult in such circumstances to control all the variables which may affect instruction. A study by Brudzynski (16) illustrates this point. He compared an inductive method where pupils learned concepts by "directed self-discovery" in a pupil-centered atmosphere to a "lecture-demonstration" teacher-centered one. The "inductive" method favored above-average students while the "lecture-demonstration" method favored average and below average students in the fifth- and sixth-grade population studied. These differences need not be ascribed to the particular instructional method. Teacher expectation may have been far more important. The less-able students may not be "expected" by the teacher, perhaps subconsciously, to perform as well in a self-directed situation. He may act in the classroom accordingly and this subconscious expectation could affect the outcomes of the students more than the instructional procedure used.

Anklam (5) identified the teachers who liked to use "democratic" instructional methods and those who preferred a more "autocratic" approach. No significant differences in achievement motivation existed between the groups of pupils taught in each of these environments. This finding points clearly to the importance of teacher characteristics and behaviors to the whole instructional procedure, and the danger of imposing a particular procedure upon teachers who do not have the personal characteristics to teach it. In this study, the teachers investigated had adopted a style of teaching which suited them. Even though the simplicity of the democratic-autocratic dichotomy may be doubted, the study did show that teachers performing within a frame of reference which they have built for themselves, motivated students equally. What is needed is research into determining instructional procedures which suit different personality types, rather than research directed to finding one procedure "best" for all teachers.

Other studies where no significant differences were found between methods used included Gerne (51) who compared a traditional textbook method with a method utilizing a specially designed board to teach electricity and magnetism, and one by Bennett (10) who compared a field method with a classroom method for teaching ecology. Smith (110) compared a lecture-demonstration style of teaching carried out in a classroom to teaching in a planetarium for presenting a lesson on astronomy concepts to sixth-grade pupils. Children in the classroom

achieved significantly higher than those taught in the planetarium. These studies suggest that the use of any visual aid or direct experience will not necessarily of itself produce significant outcome gains in children.

Carpenter (24) used fourth-grade pupils to compare a "textbook recitation method" with a "problem method." In effect, the textbook method included no demonstrations while the problem method was based on classroom demonstration and experimentation. Achievement of content gains were strongly in favor of the problem-solving method for teaching units on "magnetism" and "adaption of animals." This finding was even more definite for the slower learners—who were, in general, poor readers.

Pershern (91) investigated student achievement outcomes obtained by integrating industrial-arts activities with science instruction in grades 4, 5, 6. He used electricity and machines as his content vehicles and found significant gains in favor of integration for the electricity unit, but no significant differences for the machines unit. Integration seems to add an important dimension to instruction, and may prove a useful approach for further research.

It is difficult to generalize from comparison studies, however, it seems that pupil activity and pupil-performed experiments are important prerequisites to the effective learning of science concepts. Instructional procedures where the responsibility for the conceptual leap is placed upon the child, as in problem solving and inductive methods, do seem to bring about more significant achievement gains than do those methods where the teacher or the text material provides the concept. It appears that for these inductive methods to be fully effective, the teacher must have a certain teaching philosophy and a certain set of personal characteristics.

AUDIOVISUAL AIDS

The bulk of the research in this area involved the use of television and movie film in the classroom. How these aids can best be used in an instructional situation, what their effect is on student achievement and attitudes, and how they can improve classroom instruction are all questions to which research has been directed. Much of the research was of the "direct-comparison" type where control of all variables is extremely difficult. Conclusions based on such studies should be viewed with some caution.

Bickel (12), Decker (36), and Skinner (109) investigated changes in attitude, achievement, and interest in children following television instruction. Bickel (12) found no significant differences in the learning outcomes of his fourth-, fifth-, and sixth-grade pupils taught science by closed-circuit television incorporating a "talk-back" facility and teacher follow-up, when compared with students taught science without the aid of television.

Skinner (109) compared two television presentations for two separate groups of fifth graders. In one presentation a problem was identified, and many questions were posed which were not answered in the lesson. In this way, it was hoped that pupils' curiosity and interest in science would be aroused. The other presentation included the same materials, but used a direct expository teaching style with very few questions. Teacher follow-up of these lessons was either a modified inquiry session where the teacher answered only pupils' questions or a typical discussion session with teacher and pupils participating fully. Skinner found that pupils who experienced the television presentation with unanswered questions, regardless of teacher follow-up, achieved significantly higher than pupils who viewed "explanation" on television.

Decker (36), like Skinner, also worked with fifth graders and followed a somewhat similar procedure. He prepared two sets of ten half-hour television programs using the same materials for each. One set stressed providing information, concepts, and generalizations while the other stressed the posing of problems. No significant differences in pupil achievement were detected, so Decker concluded that the problem-solving method was as effective as the information-giving method in teaching natural science.

These conflicting results of Skinner and Decker, where one finds a significant difference in one and no significant difference in the other, point clearly to the difficulties associated with these direct-comparison type studies. They oversimplify the learning process and do not take into account how individual student needs, interests, and abilities interact with instruction. An instructional method which may be in tune with the profile of characteristics of one group of students in the class may be out of tune with another, so any gains obtained with one group will be offset by the losses in the other, and no significant differences are detected. Research on instructional procedures must be increasingly multi-dimensional, since no one method of instruction can be considered "best" for all students.

Bornhorst and Hosford (15) investigated television instruction at the third-grade level by comparing the achievement of a group of television-taught pupils with a group who had only classroom instruction. The television group achieved significantly higher results on tests than the control group, and it was felt that the "wonder-box" where children placed questions arising from the television lessons for future discussion was an important factor.

Allison (3) investigated the influence of three methods of using motivational films² on the attitudes of fourth-, fifth-, and sixth-grade students toward science, scientists, and scientific careers. He adapted the

² "Horizons of Science." Films produced by Educational Testing Service, Princeton, New Jersey.

Allen attitude inventory³ for use with these elementary school children. Allison concluded that the films did change the attitudes of the students favorably toward science, scientists, and scientific careers, and that these changes in attitude were not related to mental ability, science achievement scores, sex, science training, or the economic status of parents. This study suggests that film sequences can be devised which will effectively bring about a desired attitude change. More research in this area is needed particularly in the development and evaluation of material.

Novak (87) describes the development and use of audiotape programed instruction for teaching first- and third-grade elementary science. Cartridge tape recorders and projectors with simple "on-off" switches were used. Some of the problems associated with setting up such a program included vocabulary difficulty, pace of audio instruction, difficulty of task to be performed, density of information to be presented, inadequacies of filmloops, and unexpected distractions. Four to eight revisions of each program sequence were necessary to be sure that students could proceed with very few apparent difficulties.

Evaluation of the program was highly experimental. Individual interview using loop films, display materials, and appropriate questioning was found too time consuming. Pencil and paper tests using drawings, administered orally to the whole class, were then tried. Also, several suggestions as to future possible avenues of evaluation were developed along with other ways the materials may be used. The study leaves little doubt that audiotutorial instruction is feasible in grades one, two, and three, and should be looked on as a useful way to individualize instruction.

PROGRAMED INSTRUCTION

The role of programed instruction in the elementary school has had some attention from researchers. This is understandable since such programs encourage individual student work, and free the teacher from direct instruction to perform other tasks.

Hedges and MacDougall (61) investigated the effectiveness of teaching fourth-grade science using programed science materials and laboratory experiences. The study had three phases. In phase one, the purpose was to establish the possibility of programed instruction as a teaching method. This was done by observing students using the materials, and determining student and teacher attitudes. The information was used to revise and rewrite the programs as part of phase two of the study. The final report on the evaluative phase (phase three) has not yet come to the reviewers' attention; however, the intention was to compare innovative ways of using the materials with a more traditional approach under the headings:

³ Allen, Hugh Jr. "Attitudes of Certain High School Seniors Toward Science and Scientific Careers." Teachers College, Columbia University, New York City. 1960.

achievement, interest, problem-solving ability, ability to generalize, and retention. This three-phase method of determining feasibility, refining materials and methods, and evaluating student and teacher outcomes outlines a promising sequence for the development of instructional procedures.

Blank (14) investigated developing inquiry skills through programmed-instruction techniques. The programs trained children to ask questions about the relative dimensions of problems before attempting to solve them. He found that the children given inquiry training asked significantly more questions (as well as a lower proportion of irrelevant ones) on oral and written criterion tests than did students in control groups. This improvement in inquiry skills was not at the expense of other achievement criteria, so it was found possible to introduce inquiry training without affecting progress in regular course work.

Dutton (41) investigated pupil achievement using programmed materials on heat, light, and sound with fourth graders. He found that children did proceed at different rates and that they could perform simple science experiments with little teacher supervision. Pupils using the programmed materials learned concepts more efficiently than did those in classes taught in a conventional way.

Crabtree (30) studied the relationships between score, time, IQ, and reading level for fourth-grade students by structuring programmed science materials in different ways. Linear programs seemed preferable to branched versions since the same amount of material was learned in less time. Other findings were of the "no significant difference" type, although there was some evidence that multiple choice type response requires a higher reading ability than other response forms.

Taylor (122) investigated the effect of pupil behavior and characteristics and teacher attitudes on achievement when programmed science materials are used at the fourth-grade level. Teacher attitudes, combinations of pupil and teacher attitudes, pupil intelligence, interest, and initial knowledge of science, along with other selected personality and performance factors all contribute significantly to pupil final achievement. The study indicates that any given set of programmed science materials cannot meet the needs of all the students at any given grade level.

INDIVIDUALIZED INSTRUCTION

Instruction may be classified as individualized if experiences are specifically designed for each individual child, taking into account such factors as background, knowledge and experience, reading level, interests, and intelligence. There have been several attempts at individualizing which have tried to allow for the individual needs of children in the instructional design.

Baum (8) prepared materials to test the feasibility of individualizing

science experiences for fifth-grade pupils. He devised a series of pretests of skills and knowledge so that pupil deficiencies could be identified. Each pupil was then assigned a kit specially designed to help him acquire the skill or competency shown to be deficient on the tests. This method was found suitable for helping pupils achieve curricular goals in the area of science. Evaluation was carried out by observing pupil reactions to this instruction, and though the evaluation was subjective, the strengths of the program in terms of desired outcomes clearly emerged.

O'Toole (89) compared an individualized method with a teacher-centered approach in the teaching of science to fifth graders. He found no significant differences between his groups in achievement, problem-solving ability, or science interest. The teacher-centered program stressing problem solving as a major objective was more effective in developing the ability to identify valid conclusions while the individualized program was more effective in developing the ability to recognize hypotheses and problems.

It is likely that group methods of instruction will develop some outcomes more effectively than individualized methods, while other outcomes will develop more effectively in an individualized situation. This study was the only one which attempted to identify what some of these outcome differences might be.

Schiller (102) used activity booklets and data sheets to individualize instruction for sixth-grade pupils. The materials were designed to give children an opportunity to complete some science experiments and other activities which were in addition to the formal instructional program. Much of the evaluation was subjective, but students were eager to participate in the activities and seemed to gain from them.

Other attempts at individualizing instruction were undertaken by LaCava (69) who used the tape recorder as an aid in individualizing, Carter (25) who developed a science experience center, and Lipson (74) who developed an individualized program by coordinating audio-tapes to simple science kits. These studies, in general, support the contention that individualizing instruction is possible and educationally desirable at the elementary level. To date, however, evaluation has been highly subjective.

A more rigorous evaluation of an individualized program was undertaken by Gleason (54). He measured pupil growth in areas of general science knowledge, liking for science, and learning to generalize. Although he found no specific advantages in favor of individualized self-study activity in science, pupils learned as much content by themselves as they did when taught by a teacher.

An important project related to individualizing instruction is the Oakleaf Project for Individually Prescribed Instruction discussed by Lindvall and Bolvin (72). Here, the Oakleaf Elementary School is used as a laboratory for testing the feasibility of individualizing instruction, developing suitable programs, and evaluating the effects of such instruction.

ABILITY GROUPING—SOCIOECONOMIC STATUS OF STUDENTS

Three studies investigated the effects of socio-economic status on achievement in elementary school science. Some of the findings have clear implications for instruction.

Rowland (98) compared the science achievement of sixth-grade pupils of high socio-economic status with those of generally low status. He found that given equal intelligence and equal science background experiences, higher socio-economic status pupils show greater science achievement than do lower groups, and these differences carry over to all the various types of science achievement measured. He found that it is of great importance that lower socio-economic status pupils have opportunities to manipulate and study simple science materials, and this should precede experience with more complex types of commercial science aids. Also, these students should engage in concrete science experiences before being expected to learn from reading or discussing science material.

Wagner (124) compared the responses of economically advantaged and disadvantaged sixth-grade pupils to science demonstrations. Pupil responses to the demonstrations were obtained by getting them to either write about, tell about, or construct pictorially, using predesigned plastic templates, suitable applications of the demonstrations. Advantaged pupils were significantly superior in written and oral responses, but no differences were detected in the construction responses. This finding suggests that disadvantaged pupils understand and can communicate their understandings of science concepts when placed in situations requiring limited language response.

Becker (9) investigated the achievement of gifted sixth-grade students when segregated from, partly segregated from, or homogeneously mixed with students of lower ability. No significant differences were detected between the groups, and no special advantages accrued when gifted children were placed in special groups. Unfortunately, the description of the design of the study did not mention some important aspects, one of which was the length of time students were placed in these various arrangements. This time factor is likely to be highly significant in such a study.

These studies point to the great importance which must be placed on student characteristics in the design of instructional procedures. Selecting one factor, e.g., ability, from the whole range of factors which influence learning, and then separating instructional groups on the basis of it, is unlikely to significantly improve student outcomes. The factors involved in determining the outcomes of instruction are much more subtle than this.

USE OF READING MATERIALS

Little research was detected on investigating ways reading materials may

be used in an instructional situation. Some very interesting studies, however, were identified.

Fryback (48) evaluated some elementary science curriculum materials which had been written to accommodate five different reading levels in a fifth-grade class. Other variables in the design included whether the students performed experiments or not, and the extent of class discussion. He found that the provision for different reading ability levels and class discussion did not show any significant influence on achievement. Only when pupils worked experiments were significant achievement gains noted. The provision of different reading levels and class discussion may have a motivational effect for later work and may affect other outcomes, but these data indicate that the provision of experiments to be performed individually by pupils is important.

Bennett and Clodfelter (11) investigated student learning of earth-science concepts when the science unit was integrated within the reading program of second-grade children. For the integration, a "word-analysis" approach was used. In this method, the child was given a basic list of words to be used in the new resource unit on earth science, and then introduced to their meanings before presentation of the unit. The "word-analysis" group showed greater achievement gains than the control groups where the science was taught in the traditional way. The study demonstrated that certain earth-science concepts can be learned at the second-grade level.

Williams (128) rewrote sixth-grade science materials to a third-grade level of readability, and used them with his sixth-grade pupils. Gains in reading speed and comprehension seemed to occur when the materials were used, but the duration of the study was far too short for differences in learning outcomes to be evaluated.

Research in the area of the use of reading materials is indeed thin. More and more textbooks and other materials directed to the elementary pupil are coming onto the market, yet the role of reading materials in science instruction has had little recent evaluation.

CRITICAL THINKING

Over the period of review, only one study was identified which investigated the development of critical thinking in children. Mason (78), in a two-year study, developed materials for teaching critical thinking in grades K-6. The first year was devoted to developing materials and providing inservice seminars for the teachers who would eventually teach the course. Basic assumptions were that children should have planned experiences in science rather than incidental ones, they should have direct experience with both content and methods of science, and that experiences can be identified to give students direct training in the acquisition of scientific skills and attitudes. Evaluation of the course was subjective for grades K-3 because of the lack of suitable instruments; but,

in grades 4-6 significant gains in critical thinking were made over the period of a year. The materials were particularly effective at the fifth-grade level where maximum gains were made.

It seems quite clear that instructional sequences can be devised which will develop pupils' powers of critical thinking. Only by evaluating the outcomes of the experiences can the effectiveness of these materials be assessed. There is a lack of activity in this area, particularly in grades K-3.

PROCESS: INQUIRY IN SCIENCE

Much emphasis has been placed on the development of science process skills and the use of inquiry methods to develop certain cognitive abilities by the new elementary science course improvement projects. Less research has been reported in this area than might have been expected if one judges from the significant sums of money spent on developing these programs.

Raun (95) investigated the interaction between curriculum variables and selected classroom-student characteristics using the AAAS *Science - A Process Approach* materials. He was interested in the changes in cognitive and affective behavior brought about by children using some of the strategies of science. Some of the factors investigated included problem solving, perceptual closure, verbal fluency, ideation fluency, tested intelligence, achievement, and attitudes toward science and scientists. The strategies of inquiry selected for performance evaluation after five months instruction were classifying, observing, using number relations, and recognizing space-time relations. He found limited evidence of significant grade differences between behaviors and performance in the strategies of inquiry in science, and that there was no consistent pattern of behavioral change among grades. In fact, on many of the factors investigated, grades 5 and 6 showed regressive tendencies which support the argument that there is rather slow development of science process skills beyond grade 5.

Price (93) investigated whether students who had manipulated objects and materials to gather empirical data in an elementary classroom would transfer this manipulative process behavior to a test situation outside the classroom. It was found that children rarely sought data by overt manipulative processes in the test situations, even though verbal responses to them indicated high motivational interest. Also gifted children showed no greater tendency to empirically gather data to solve problems than students in the normal range of intelligence.

Scott and Sigel (106) used grades 4-6 to investigate the effects of inquiry training in physical science on creativity and cognitive style. Pupils receiving inquiry training learned science concepts as well or better than children in conventional classes, and no significant differences were found between boys and girls. Cognitive styles did seem to be influenced by the inquiry process, and some differences in the developmental trends of cognitive styles of boys compared to girls were apparent.

More studies like the above are needed if instructional procedures are to be developed which meet the individual needs of students at each stage in their development. Inquiry methods and methods designed to have children working with the processes of science are likely to produce different outcomes than conventional procedures. These new procedures are becoming more carefully controlled, and with the development of more sensitive evaluative instruments, a clearer idea of what these differences may be is starting to emerge. Increased research on ways the new materials may be used and the outcomes obtained seems essential.

PROBLEM SOLVING

A number of studies investigated problem solving in elementary children. Dyrli (42), Gunnels (55), and Harris (59) all made some analysis of the problem-solving behavior of children at various grade levels. Only Schippers (103) extended what is known about problem solving into a suggested instructional sequence.

Dyrli (42) wished to discover whether instruction had any effect on the length of transition period from the stage of concrete operations to more formal patterns of thought in the Piagetian developmental sequence. Gunnels (55) also investigated cognitive development based on the Piagetian stages of intuitive, concrete, and formal thought. He used an interview technique to study the development of logical judgments in science of successful and unsuccessful problem solvers in grades 4-9. In general, the Piagetian order of development was confirmed that successful problem solvers operate at a higher level of operational thought than do unsuccessful problem solvers; however, even though a child is at a given chronological age, this does not guarantee a definite level of thought process skills.

Harris (59) used sixth graders and investigated the usefulness of pupil drawings in developing a problem-solving approach to learning science concepts. He identified two kinds of problem-solving behavior; verificational and insightful, but his study concentrated on the verificational aspects which seem most often encountered in school. He made an intensive individual analysis of the problem-solving processes of eighteen children. Some of his findings are pertinent to the development of instructional procedures. He found that children do not use consistent patterns of thinking in different problem situations, and that the confidence of the child in his ability to solve problems is an important factor in his success. Also instruction in science, which includes drawing of concepts in a tangible form by the learner, was not significantly related to growth in the ability of the learner to use these concepts in problem-solving situations. A particularly significant finding relating to the evaluation of an instructional sequence was that pencil and paper tests did not provide an adequate means for evaluating problem-solving processes in individual children.

Schippers (103) designed materials and a procedure to teach sixth graders a problem-solving instructional method using a multi-reference activity base. Three steps in the instructional process were identified: first, establish the background situation; second, understand the problem, and third, work out a solution. Supervision and the use of illustrative lessons were found important if inexperienced teachers were to use the method effectively. Evaluation of student outcomes was largely subjective.

CREATIVITY

Only two studies were identified which made an attempt to develop materials and procedures for encouraging creativity and creative thinking in students.

DeRoche (37) used creative exercises with sixth-grade pupils to see if these produced any gains in creative thinking and achievement not seen in classes doing more traditional work. The experimental group had creative exercises in 26 space science lessons and four "brain-storming" sessions, while control classes either had 30 space science lessons without the exercises or no space science instruction at all. The *Minnesota Tests of Creative Thinking* and specially prepared content achievement tests were used to evaluate outcomes. For high intelligence students, the experimental method was significantly superior to the control in developing creative factors like verbal fluency, flexibility, originality, and elaboration. This trend was less marked for average and low ability students. No significant differences on the achievement tests were found between the "creative" group and the "traditional" group taught space science.

Tating (121) studied ways of developing creative thinking in elementary school science. Creative thinking was defined operationally as divergent and original thinking measured in terms of questions asked and hypotheses given. More divergent responses were obtained with the trained groups than with the control, but the number of divergent responses decreased if pupils were given instructions to be original. Tating "primed" creative thinking by getting pupils to write down as many questions as they could about a particular demonstration, which, if given a "yes-no" answer by the teacher, would help the child understand why a given event occurred. Another method of priming used was to get students to write down a number of words in response to a given word.

Although the asking of questions could be primed, the development of hypotheses was not as responsive to training. The formulation of hypotheses in science is a highly complicated mental process, and the formation of an original hypothesis probably requires more time than is needed to think of questions.

The evidence is mounting that creative exercises can be designed to increase creative responses in children without any losses in content

achievement. Teachers are constantly being urged to teach science creatively, and more research needs to be done to estimate the effectiveness of various forms of instruction.

CONCEPT DEVELOPMENT

Many of the studies in this area were concerned with concept development as part of research into learning theory, rather than evaluating different instructional procedures for their efficiency in developing concepts.

Voelker (123) gives an example of pertinent research on the development of concepts within the field of science education. He compared two instructional methods for teaching the concepts of physical and chemical change in grades 2-6. Using essentially similar lesson procedures and materials in both cases, he found that formulation and statement by the teacher of the generalization to be learned was not superior to a procedure in which the pupil individually formulated the generalization concerning physical and chemical change. An interesting sidelight of the study was that although sixth-grade pupils were significantly better verbalizers of the concepts, if the criterion of understanding was simply to classify observed phenomena, no significant differences could be detected among grades 2-6. In this study, where teaching method and materials were carefully controlled, there did not seem to be any significant advantages of an "inductive-discovery" approach over a "deductive" one on the outcomes selected. Unfortunately, the concept of physical and chemical change appeared rather difficult except for pupils in grade 6.

Salstrom (100) compared concepts learned by sixth-grade pupils in two types of guided discovery lessons. The same experimental lessons were presented as a science game to each of his groups. Following this, one group had an oral inquiry session while the other received a battery of cards which on one side had printed questions a pupil might ask in an inquiry session and on the other, the answers to those questions were printed. In the card group, each pupil could draw only cards that would yield information needed to solve the problem. They were then ordered by the pupil to give a solution to the problem posed in the lesson. The card treatment group showed greater gains in concept development than the oral inquiry group, supporting the contention that the more guidance that can be given each pupil in an oral inquiry session helps concept development.

Three studies were directed at finding the relationship between the child's level of maturity and the understanding of a particular concept. Carey (21) investigated the particle nature of matter in grades 2-5, Haddad (56) investigated the concept of relativity in grades 4-8, and Helgeson (62)

investigated the concept of force. Maturity studies like these are extremely useful in helping course developers decide the level to which a particular concept may be unfolded with pupils at a particular stage in development. The studies suggested that there was almost as much variation in maturity within a grade level as there was between grade levels. These data question the grouping of children by grades if the aim is to provide a group of children at the same stage of mental development.

Kolb (66) investigated integrating mathematics and science instruction with fifth-grade pupils to determine if such integration would facilitate the acquisition of quantitative science behaviors. He used *Science—A Process Approach* materials and found that such integration with mathematics did significantly increase achievement. Integration seems a promising way to reduce the time spent in developing concepts which have elements common to both mathematics and science, and this aspect should be pursued further.

Ziegler (132) investigated the use of mechanical models in teaching theoretical concepts regarding the particle nature of matter to pupils in grades 2-6. They found that children who had not previously learned to use such a model could learn to do so with suitable instruction, and those who had some knowledge of such models improved their ability to use them. These concrete experiences with mechanical models helped pupils form theoretical concepts to explain expansion, contraction, change of phase, and mixtures by the time they completed grade 4.

Studies like this and those of Carey (21), Haddad (56), Voelker (123), and Helgeson (62) should be extended into other concept areas so that a more complete picture of the concepts which may be developed at any given level may emerge. From this, suitable instructional procedures using mechanical models and other devices can be developed. Until this is done, courses of instruction in elementary schools will be based on subjective opinion and feeling about what can be accomplished at any given grade level or stage of development, rather than on a soundly researched experimental base.

SUMMARY AND CONCLUSIONS

Reviewing the available research into the outcomes of instruction in elementary science has revealed a number of areas where little in the way of a planned attack on the problems has been initiated. Such areas include the development of psychomotor skills, critical thinking skills, creativity, and work in the affective domain on the development of attitudes toward science and scientists. Only in the field of understanding concepts can one see steady progress being made.

The tentative nature of the findings of much educational research and the massive qualifications which surround any generalizations made by

researchers often appear confusing to the classroom teacher. In light of this, the reviewers have decided to outline a number of tentative conclusions which seem to emerge from the research reviewed.

1. Instructional procedures, whether in the classroom or in the research situation, should be based on some clearly defined model of what constitutes the instructional process. The major criteria for such a model should be that it is useful in helping understand the components of instruction and that the instruction develops desired behavior changes in pupils.
2. For teachers skilled in handling them, problem-solving or inductive methods or instructional procedures designed to improve creativity can bring about gains in outcome areas which are greater than if more traditional approaches are used. This is not achieved at the expense of knowledge of content.
3. Audiovisual aids and reading materials should be carefully integrated into the instructional sequence for a definite instructional purpose, otherwise little effect on achievement outcomes will be noted.
4. Pupil activity and pupil performed experiments are important prerequisites for the effective learning of science concepts. This seems true for all levels of ability.
5. Instructional procedures can be devised to bring about specific outcomes, provided these outcomes are clearly defined. Both problem-solving skills and creativity can be developed.
6. Individualized instruction is a satisfactory alternative to total class instruction. Even very young children can work alone on preplanned experiences using quite sophisticated aids with minimal teacher help.
7. Elementary children can learn by using programmed instruction materials. Outcomes from these are enhanced if they are integrated with laboratory experiences.
8. Each child should have the opportunity to develop science concepts and process skills in both individual and group situations. The outcomes of one kind of instruction will complement rather than parallel the other.
9. Verbalization of a concept is the last step in a child's understanding of it. He can demonstrate aspects of his understanding in concrete situations long before he can verbalize them.
10. Any given class in elementary school is likely to contain children who are in at least two stages of cognitive development—that of concrete operations and formal thought. These two groups require quite different instructional strategies.
11. Ability grouping has little effect on the achievement of high ability students. Other student characteristics are just as significant as intelligence in the learning process.

12. Educationally disadvantaged students can communicate their understanding of science concepts if the response mode is by a means other than language; e.g., pictorial representation.
13. Integration of mathematics and science saves time. Where common concepts are being developed, achievement in both areas seems to be enhanced.
14. Educationally disadvantaged children need even greater recourse to simple materials and individual experiments if they are to develop the desired science concepts to the level of other children.
15. Teachers should decide on instructional procedures which suit their own personal characteristics and philosophy. Modification of firmly established patterns of teaching can only occur if there is a corresponding modification of personal characteristics and behaviors.

References

1. Ainslie, D. S. "Simple Equipment and Procedures in Elementary Laboratories." *The Physics Teacher*. September 1967.
2. Allen, Leslie Robert. "An Examination of the Classificatory Ability of Children Who Have Been Exposed to One of the 'New' Elementary Science Programs." (M)⁴. 1967.
3. Allison, Roy W. "The Effect of Three Methods of Treating Motivational Films Upon the Attitudes of Fourth-, Fifth-, and Sixth-Grade Students Toward Science, Scientists, and Scientific Careers." Pennsylvania State University, 1967.
4. Anderson, Ronald D. "Children's Ability to Formulate Mental Models to Explain Natural Phenomena." *Journal of Research in Science Teaching*. December 1965.
5. Anklaam, Phoebe Anne. "A Study of the Relationship between Two Divergent Instructional Methods and Achievement Motivation of Elementary School Children." (M). 1962.
6. Barker, D. "Primary School Science—An Attempt to Investigate the Effects of the Informal Use of a Discovery Table on the Scientific Knowledge of Primary School Children." *Educational Research*. February 1965.
7. Barrett, Raymond E. "Field Trip Tips." *Science and Children*. October 1965.
8. Baum, Ernest A. "Report of the Individualization of the Teaching of Selected Science Skills and Knowledges in an Elementary School Classroom with Materials Prepared by the Teacher." (M). 1965.
9. Becker, Leonard John. "An Analysis of the Science and Mathematics Achievement of Gifted Sixth-Grade Children Enrolled in Segregated Classes." (M). 1963.
10. Bennett, Lloyd M. "A Study of the Comparison of Two Instructional Methods, the Experimental-Field Method and the Traditional Classroom Method, Involving Science Content in Ecology for the Seventh Grade." *Science Education*. December 1965.

⁴ (M) denotes University Microfilms, Ann Arbor, Michigan.

11. Bennett, Lloyd M. and Cherie Clodfelter. "A Study of the Integration of an Earth Science Unit Within the Reading Program of a Second Grade by Utilizing the Word Analysis Approach." *School Science and Mathematics*. November 1966.
12. Bickel, Robert F. "A Study of the Effect of Television Instruction on the Science Achievement and Attitudes of Children in Grades 4, 5, and 6." (M). 1964.
13. Blackwood, Paul E. "Science Teaching in the Elementary School: A Survey of Practices." *Journal of Research in Science Teaching*. September 1965.
14. Blank, Stanley Solomon. "Inquiry Training Through Programed Instruction." (M). 1963.
15. Bornhorst, Ben A., and Prentiss M. Hosford. "Basing Instruction in Science on Children's Questions: Using a Wonder Box in the Third Grade." *Science Education*. March 1960.
16. Brudzynski, Alfred John. "A Comparative Study of Two Methods for Teaching Electricity and Magnetism with Fifth- and Sixth-Grade Children." (M). 1966.
17. Brusini, Joseph Anthony. "An Experimental Study of the Development of Science Continuum Concepts in Upper Elementary and Junior High School Children." (M). 1966.
18. Buell, Robert R. "Inquiry Training in the School's Science Laboratories." *School Science and Mathematics*. April 1965.
19. Butts, David P. "The Degree to Which Children Conceptualize from Science Experiences." *Journal of Research in Science Teaching*. June 1962.
20. Butts, David P. "The Relationship Between Classroom Experiences and Certain Student Characteristics." University of Texas, February 1967.
21. Carey, Russell LeRoy. "Relationship Between Levels of Maturity and Levels of Understanding of Selected Concepts of the Particle Nature of Matter." (M). 1967.
22. Carlson, Jerry S. "Effects of Instruction on the Concepts of Conservation of Substance." *Science Education*. March 1967.
23. Carpenter, Finley. "Toward a Systematic Construction of a Classroom Taxonomy." *Science Education*. April 1965.
24. Carpenter, Regan. "A Reading Method and an Activity Method in Elementary Science Instruction." *Science Education*. April 1963.
25. Carter, Neal. "Science Experience Center." *Science and Children*. February 1967.
26. Caruthers, Bertram, Sr. "Teacher Preparation and Experience Related to Achievement of Fifth-Grade Pupils in Science." (M). 1967.
27. Chinnis, Robert Jennings. "The Development of Physical Science Principles in Elementary-School Science Textbooks." (M). 1962.
28. Cobun, Ted Charles. "The Relative Effectiveness of Three Levels of Pictorial Presentation of Biological Subject Matter on the Associative Learning of Nomenclature by Sixth-Grade Students." (M). 1961.
29. Cox, Louis T. "Working with Science in the Kindergarten." *Science Education*. March 1963.
30. Crabtree, J. F. "A Study of the Relationships Between 'Score,' 'Time,' 'IQ,' and 'Reading Level' for Fourth-Grade Students Using Programed Science Materials." *Science Education*. April 1967.
31. Crabtree, Charlotte Antoinette. "Effects of Structuring on Productiveness in Children's Thinking: Study of Second-Grade Dramatic Play Patterns Centered on Harbor and Airport Activities Under Two Types of Teacher Structuring." (M). 1962.

32. Cunningham, Roger. "Implementing Nongraded Advancement with Laboratory Activities as a Vehicle—An Experiment in Elementary School Science." *School Science and Mathematics*. February 1967.
33. Cunningham, John D. "On Curiosity and Science Education." *School Science and Mathematics*. December 1966.
34. Dart, Francis E., and Panna Lal Pradham. "Cross-Cultural Teaching of Science." *Science*. February 1967.
35. Davis, Joseph E., Jr. "Ice Calorimetry in the Upper Elementary Grades." *Science and Children*. December 1966.
36. Decker, Martin George. "The Differential Effects Upon the Learning of the Natural Sciences by Fifth Graders of Two Modes of Teaching over Television and in the Classroom." (M). 1965.
37. DeRoche, Edward Francis. "A Study of the Effectiveness of Selected Creative Exercises on Creative Thinking and the Mastery of a Unit in Elementary Science." (M). 1966.
38. Dietmeier, Homer J. "The Effect of Integration of Science Teaching by Television on the Development of Scientific Reasoning in the Fifth-Grade Student." (M). 1962.
39. Downing, Carl Edward. "A Statistical Examination of the Relationship Among Elementary Science Achievement Gains, Interest Level Changes, and Time Allotment for Instructional Purposes." (M). 1963.
40. Drenchko, Elizabeth K. "The Comparative Effectiveness of Two Methods of Teaching Grade School Science." (M). 1966.
41. Dutton, Sherman S. "An Experimental Study in the Programing of Science Instruction for the Fourth Grade." (M). 1963.
42. Dyrli, Odvard Egil. "An Investigation into the Development of Combinational Mechanisms Characteristic of Formal Reasoning, Through Experimental Problem Situations with Sixth-Grade Students." (M). 1967.
43. Eccles, Priscilla J. "Research Reports—Teacher Behavior and Knowledge of Subject Matter in Sixth-Grade Science." *Journal of Research in Science Teaching*. December 1965.
44. Elashhab, Gamal A. "A Model for the Development of Science Curricula in the Preparatory and Secondary Schools of the United Arab Republic." (M). 1966.
45. Engelmann, Siegfried, and James J. Gallagher. "A Study of How a Child Learns Concepts About Characteristics of Liquid Materials." EDRS, National Cash Register Company, 1966.
46. Fischler, Abraham S. "Science, Process, The Learner—A Synthesis." *Science Education*. December 1965.
47. Fish, Alphoretta S., and Bernice Goldmark. "Inquiry Method—Three Interpretations." *The Science Teacher*. February 1966.
48. Fryback, William H. "Evaluation of Multi-Level Reading Materials, Intra-Class Discussion Techniques and Student Experimentations on Achievement in Fifth-Grade Elementary Science." (M). 1965.
49. Garone, John Edward. "Acquiring Knowledge and Attaining Understanding of Children's Scientific Concept Development." *Science Education*. March 1960.
50. Gehrman, Joseph Leo. "A Study of the Impact of Authoritative Communication of Expected Achievement in Elementary School Science." (M). 1965.

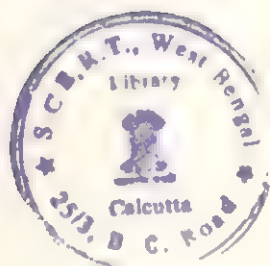
51. Gerne, Timothy A., Jr. "A Comparative Study of Two Types of Science Teaching on the Competence of Sixth-Grade Students to Understand Selected Topics in Electricity and Magnetism." (M). 1967.
52. Glaser, Robert. "Concept Learning and Concept Teaching." University of Pittsburgh, Learning Research and Development Center. 1967.
53. Glaser, Robert. "The Design of Instruction." National Society for the Study of Education Yearbook, 1966.
54. Gleason, Walter Patterson. "An Examination of Some Effects of Pupil Self-Instruction Methods Compared with the Effects of Teacher-Led Classes in Elementary Science of Fifth-Grade Pupils." (M). 1965.
55. Gunnels, Frances Goodrich. "A Study of the Development in Logical Judgments in Science of Successful and Unsuccessful Problem Solvers in Grades Four Through Nine." (M). 1967.
56. Haddad, Wadi Dahir. "Relationship Between Mental Maturity and the Level of Understanding of Concepts of Relativity in Grades 4-8." (M). 1968.
57. Harris, William, and Verlin Lee. "Mental Age and Science Concepts—A Pilot Study." *Journal of Research in Science Teaching*. December 1966.
58. Harris, William. "A Technique for Grade Placement in Elementary Science." *Journal of Research in Science Teaching*. March 1964.
59. Harris, William Ned. "An Analysis of Problem-Solving Behavior in Sixth-Grade Children, and of the Usefulness of Drawings by the Pupil in Learning Science Concepts." (M). 1962.
60. Haugerud, Albert Ralph. "The Development of a Conceptual Framework for the Construction of a Multi-Media Learning Laboratory and Its Utilization for Elementary School Science." (M). 1966.
61. Hedges, William D., and Mary Ann MacDougall. "Teaching Fourth-Grade Science by Means of Programed Science Materials with Laboratory Experiences." *Science Education*. February 1964.
62. Helgeson, Stanley Leon. "An Investigation into the Relationships Between Concepts of Force Attained and Maturity as Indicated by Grade Levels." (M). 1967.
63. Hinmon, Dean E. "Problem Solving." *Science and Children*. April 1966.
64. Johnson, Mervin LeRoy. "A Determination of Aerospace Principles Desirable for Inclusion in Fifth- or Sixth-Grade Science Programs." (M). 1966.
65. Karplus, Robert. "Science Curriculum Improvement Study." *Journal of Research in Science Teaching*. December 1964.
66. Kolb, John R. "Effects of Relating Mathematics to Science Instruction on the Acquisition of Quantitative Science Behaviors." *Journal of Research in Science Teaching*. 1968.
67. Korey, Ruth Anne. "Contributions of Planetariums to Elementary Education." (M). 1963.
68. Kraft, Mary Elizabeth. "A Study of Information and Vocabulary Achievement from the Teaching of Natural Science by Television in the Fifth Grade." (M). 1961.
69. LaCava, George. "An Experiment Via Tape." *Science and Children*. October 1965.
70. Languis, Marlin, and Loren L. Stull. "Science Problems—Vehicles to Develop Measurement Principles." *Science Education*. February 1966.

71. Lansdown, Brenda, and Thomas S. Dietz. "Free Versus Guided Experimentation." *Science Education*. April 1965.
72. Lindvall, C. Mauritz, and John D. Bolvin. "Individually Prescribed Instruction—The Oakleaf Project." University of Pittsburgh, Learning Research and Development Center, February 1966.
73. Lipson, Joseph I. "Light Test—Comparison Between Elementary School Children and College Freshman." University of Pittsburgh, Learning Research and Development Center. February 1966.
74. Lipson, Joseph I. "An Individualized Science Laboratory." *Science and Children*. December 1966.
75. Livermore, Arthur H. "The Process Approach of the AAAS Commission on Science Education." *Journal of Research in Science Teaching*. December 1964.
76. Lowery, Lawrence F. "An Experimental Investigation into the Attitudes of Fifth-Grade Students Toward Science." *School Science and Mathematics*. June 1967.
77. Los Angeles City Schools. "The Art of Questioning in Science—Summary and Implications." Los Angeles City Schools. 1967.
78. Mason, John M. "The Direct Teaching of Critical Thinking in Grades Four Through Six." *Journal of Research in Science Teaching*. December 1963.
79. McCloskey, James. "The Development of the Role of Science in General Education for Elementary and Secondary Schools." (M). 1963.
80. McKeon, Joseph E. "A Process Lesson in Density." *Science and Children*. December 1966.
81. Melis, Lloyd Henry. "The Nature and Extent of Reading Instruction in Science and Social Studies in the Intermediate Grades of Selected School Districts." (M). 1964.
82. Mermelstein, Egon; Edwina Carr; Dorothy Mills; and Jeanne Schwartz. "The Effects of Various Training Techniques on the Acquisition of the Concept of Conservation of Substance." U.S. Department of Health, Education, and Welfare, February 1967.
83. Moorehead, William D. "The Status of Elementary School Science and How It Is Taught." (M). 1965.
84. Nasca, Donald. "Effect of Varied Presentations of Laboratory Exercises Within Programed Materials on Specific Intellectual Factors of Science Problem-Solving Behavior." *Science Education*. December 1966.
85. Neal, Louise A. "Techniques for Developing Methods of Scientific Inquiry in Children in Grades One Through Six." *Science Education*. October 1961.
86. New York State Department of Education. "Tips and Techniques in Elementary Science." Bureau of Elementary Curriculum Development. 1966.
87. Novak, Joseph D. "Development and Use of Audio-Tape Programed Instruction for Elementary Science." Purdue University, February 1967.
88. O'Toole, Raymond J. "A Review of Attempts to Individualize Elementary School Science." *School Science and Mathematics*. May 1968.
89. O'Toole, Raymond J. "A Study to Determine Whether Fifth-Grade Children Can Learn Certain Selected Problem-Solving Abilities Through Individualized Instruction (Research Study Number 1)." (M). 1966.
90. Perkins, William D. "The Field Study as a Technique in Elementary School Science." *Science Education*. December 1963.

91. Pershern, Frank Richard. "The Effect of Industrial Arts Activities on Science Achievements and Pupil Attitudes in the Upper Elementary Grades." (M). 1967.
92. Pollach, Samuel. "Individual Differences in the Development of Certain Science Concepts." (M). 1963.
93. Price, LaMar. "An Investigation of the Transfer of an Elementary Science Process." (M). 1968.
94. Ramsey, Irvin L., and Sandra Lee Wiandt. "Individualizing Elementary School Science." *School Science and Mathematics*. May 1967.
95. Raan, Chester Eugene. "The Interaction Between Curriculum Variables and Selected Classroom Student Characteristics." (M). 1967.
96. Reese, Willard Francis. "A Comparison of Interest Level and Problem-Solving Accuracy Generated by Single Concept Inductive and Deductive Science Films (Research Study Number 1)." (M). 1966.
97. Riessman, Frank. "Education of the Culturally Deprived Child." *The Science Teacher*. November 1965.
98. Rowland, George William. "A Study of the Relationship Between Socio-Economic Status and Elementary School Science Achievement." (M). 1965.
99. St. John, Clinton. "Can Science Education Be Scientific? Notes Toward a Viable Theory of Science Teaching." *Journal of Research in Science Teaching*. December, 1966.
100. Salstrom, David. "A Comparison of Conceptualization in Two Types of Guided Discovery Science Lesson." (M). 1966.
101. Sands, Theodore; Robert E. Rumery; and Richard C. Youngs. "Concept Development Materials for Gifted Elementary Pupils - Final Report of Field Testing." Illinois State University. 1966.
102. Schiller, LeRoy. "A Study of the Effect of Individualized Activities on Understanding in Elementary School Science." (M). 1964.
103. Schippers, John Vernon. "An Investigation of the Problem Method of Instruction in Sixth-Grade Science Classes." (M). 1962.
104. Shulz, Richard William. "The Role of Cognitive Organizers in the Facilitation of Concept Learning in Elementary School Science." (M). 1966.
105. Scott, Lloyd. "An Experiment in Teaching Basic Science in the Elementary School." *Science Education*. March 1962.
106. Scott, Norval C., Jr., and I. E. Sigel. "Effects of Inquiry Training in Physical Science on Creativity and Cognitive Styles of Elementary School Children." U.S. Office of Education, Cooperative Research Branch, 1965.
107. Scott, Norval, C., Jr. "Science Concept Achievement and Cognitive Functions." *Journal of Research in Science Teaching*. December 1964.
108. Scott, Norval, C., Jr. "The Strategy of Inquiry and Styles of Categorization." *Journal of Research in Science Teaching*. September 1966.
109. Skinner, Ray, Jr. "An Experimental Study of the Effects of Different Combinations of Television Presentations and Classroom Teacher Follow-up on the Achievement and Interest in Science of Fifth Graders." (M). 1966.
110. Smith, Billy Arthur. "An Experimental Comparison of Two Techniques (Planetarium Lecture-Demonstration and Classroom Lecture-Demonstration) of Teaching Selected Astronomical Concepts to Sixth-Grade Students." (M). 1966.
111. Smith, Doyne M. and Bernice Cooper. "A Study of the Use of Various

- Techniques in Teaching Science in the Elementary School." *School Science and Mathematics*. June 1967.
112. Smith, Robert Frank. "An Analysis and Classification of Children's Explanations of Natural Phenomena." (M). 1963.
 113. Snoble, Joseph Jerry. "Status and Trends of Elementary School Science in Iowa Public Schools, 1963-1966." (M). 1967.
 114. Stapp, William Beebe. "Developing a Conservation Education Program for the Ann Arbor Public School System, and Integrating It into the Existing Curriculum (K-12)." (M). 1963.
 115. Stauss, Nyles George. "An Investigation into the Relationship Between Concept Attainment and Level of Maturity." (M). 1967.
 116. Stokes, William Woods. "An Analysis and Evaluation of Current Efforts to Improve the Curriculum by Emphasis on Disciplinary Structure and Learning by Discovery." (M). 1963.
 117. Stone, Ruth Muriel. "A Comparison of the Patterns of Criteria Which Elementary and Secondary School Teachers Use in Judging the Relative Effectiveness of Selected Learning Experiences in Elementary Science." (M). 1963.
 118. Suchman, J. Richard. "Idea Book—Inquiry Development Program in Physical Science." Science Research Associates, Inc., Chicago. 1966.
 119. Suchman, J. Richard. "Inquiry Training: Building Skills for Autonomous Discovery." *Merrill-Palmer Quarterly*. 1961.
 120. Swan, Malcolm D. "Science Achievement as It Relates to Science Curricula and Programs at the Sixth-Grade Level in Montana Public Schools." *Journal of Research in Science Teaching*. June 1966.
 121. Tating, Marcela Tionko. "Priming Creative Thinking in Elementary School Science." (M). 1965.
 122. Taylor, Alton L. "The Influence of Teacher Attitudes on Pupil Achievement with Programed Science Materials." *Journal of Research in Science Teaching*. March 1960.
 123. Voelker, Alan Morris. "The Relative Effectiveness of Two Methods of Instruction in Teaching the Classificational Concepts of Physical and Chemical Change to Elementary School Children." (M). 1967.
 124. Wagner, Bartlett Adam. "The Responses of Economically Advantaged and Economically Disadvantaged Sixth-Grade Pupils to Science Demonstrations." (M). 1967.
 125. Walbesser, Henry H. "Science Curriculum Evaluation—Observations on a Position." *The Science Teacher*. February 1966.
 126. Walbesser, Henry H., et al. "Science—A Process Approach, An Evaluation Model and Its Application—Second Report." American Association for the Advancement of Science, AAAS Miscellaneous Publication 68-4. 1968.
 127. Washton, Nathan S. "Teaching Science for Creativity." *Science Education*. February 1966.
 128. Williams, David Lee. "The Effect of Rewritten Science Textbook Materials on the Reading Ability of Sixth-Grade Pupils." (M). 1964.
 129. Wilson, John Harold. "Differences Between the Inquiry-Discovery and the Traditional Approaches to Teaching Science in Elementary Schools." (M). 1967.
 130. Wolinsky, Gloria F. "Science Education and the Severely Handicapped Child." *Science Education*. October 1965.

131. Zaffaroni, Joseph. "A Study of Pupil-Teacher Interaction in Planning Science Experiences." *Science Education*. March 1963.
132. Ziegler, Robert Edward. "The Relative Effectiveness of the Use of Static and Dynamic Mechanical Models in Teaching Elementary School Children the Theoretical Concept—The Particle Nature of Matter." (M). 1967.



THE EVALUATION OF ELEMENTARY SCIENCE

INTRODUCTION

If the elementary science program is to be effective, then the program should be evaluated continuously. Definite and adequate provision should be made to ensure that the evaluation is dynamic and continuous rather than perfunctory and sporadic. All those who participate in the science program should be involved in the evaluation, and not just a small committee of teachers specifically appointed for that purpose. This is especially important when the elementary science program is part of a total K 12 program. Then the program should be evaluated by the elementary and secondary school teachers, by the science supervisor or consultant, and by the curriculum director, because all these persons are responsible for determining the content of the program.

If there is a curriculum guide, it too should be evaluated continuously. Teachers should be encouraged to evaluate the contents of the guide critically as they use it, and to forward criticisms and recommendations to the persons or committee responsible for conducting the evaluation and revision of the guide. The science content of the guide should be examined carefully for corrections, additions, or deletions. The sequence of topics in the guide should be checked for appropriate grade placement. Initiating activities should be evaluated for motivating and problem-raising potential. Learning activities should be tested critically to see if they are producing maximum learning, and should be replaced by newer, more creative activities as they appear in text and reference books. Even the evaluation techniques themselves should be scrutinized regularly.

In the classroom good teaching and learning call for continuous evaluation by both the teacher and the children. The teacher should constantly evaluate the content being learned, and also the methods and materials being used, to see if the children are achieving the objectives of the science program. The children should be encouraged to evaluate continually their strengths and weaknesses, their progress and growth in science learning, and their proficiency with the key operations, or processes, of science and the scientist.

Evaluation in the classroom can be used for a variety of purposes. First, it can be used to appraise achievement, by determining how well the children have learned science concepts and how competent they have become in performing the operations of the scientist. Second, it can be used for diagnostic purposes. As such, it can help identify the children's strengths and weaknesses. It can determine how well the children can work individually and in groups. It can be used as a pretest to learn how much the children already know about a topic before they begin the study of this topic. It can be used to diagnose the effectiveness of the teaching methods being used. Sometimes one method is more effective than another for different groups of children. Third, evaluation can be used for predictive purposes, where the teacher attempts to predict the children's behavior and achievement in the future or under different conditions.

There are a variety of methods of evaluation which the elementary school teacher can use. These methods are grouped into three categories: oral methods, written methods, and observation methods. Teachers may vary in their preference, but there is no one single best method of evaluating science learning. Actually, the objectives to be evaluated are more important than the method used, and very often the desired objectives or outcomes of learning will help determine which method should be selected. Also, the teacher should keep in mind that good test questions can be difficult and time-consuming to prepare, so tests should be constructed with much thought and care.

THE EVALUATION OF THE ELEMENTARY SCIENCE PROGRAM

National Society for the Study of Education

A total elementary science program must be evaluated by all who participate in the program. Such evaluation must include children, teachers, supervisors or consultants, and administrators. Evaluation should be planned and should be a constant process. It can take place only after the characteristics of a good program are established. The following article presents eight such characteristics and the criteria for their evaluation. This article is an excerpt from Chapter 7, "Developing Science Programs in the Elementary School," of the Fifty-ninth Yearbook, Part I, of the National Society for the Study of Education, Rethinking Science Education. Members of the committee who wrote this chapter include Glenn. O. Blough, Paul E. Blackwood, Katherine E. Hill, and Julius Schwartz.

A program in elementary science can be effectively evaluated only when the objectives of a program are clear and have been accepted by the teachers and administrators in charge of the program. Too often the goals of a program are listed by a committee, printed at the beginning of a course of study, and then forgotten. Once goals have been accepted, they should be used as a basis for the selection of subject matter and the methods of teaching. If this is done, the adequacy of the program may be evaluated, at least in terms of its goals. Such appraisal may lead to redefinition of purposes and the establishment of new goals, which in turn may reasonably be expected to lead to experimenting with different teaching methods and subject matter. This is a process by which educational programs can be improved continuously.

Many curriculum guides and resource units include suggestions for evaluation. Some of the manuals for the development of courses of study that have been produced by state departments of education contain excellent suggestions for evaluation. However, few systematic attempts at evaluation of elementary-science programs have been reported.

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WHO EVALUATES? If the evaluation of a total program in elementary science is sought, then all who participate in the program should be involved in the evaluation of it. Too often segments of the program have been evaluated in discrete units only by those most closely connected with the particular parts examined. For example, fifth-grade teachers in a school system have regularly evaluated the science taught in the fifth grades only. At times, the evaluation has been limited to the appraisal of the elementary-school program in science by the elementary-school faculty. This is too limited a group to evaluate elementary science as an integral part of a science program extending from the Kindergarten through Grade XII. A total science program must be assessed by elementary- and secondary-school teachers, by consultants in elementary science if they operate in the system, and by those administrators who are responsible for the development of curriculum. These are the persons primarily responsible for the selection of methods and content. All must be involved in the evaluation of the acceptability of the elementary-science program.

But the learner must not be forgotten. He must have a part in the evaluative process. Involving elementary-school children in assessing the program in science is a difficult undertaking, since their appraisal is apt to be related only to their most recent science experiences. Even so, the judgment of children may lead to reappraisal of a program. Older children, especially those in the upper-elementary grades and in the secondary school, may be used in helping the teaching and curriculum staffs find strong and weak features of the elementary-science program.

A third group sometimes involved in judging the merits of a program in elementary science is composed of parents and other members of the community. Often, they make judgments of the value of various aspects of the science program. At times, their judgments result in pressure being applied to influence school programs. The evaluation by members of the community may contribute to the over-all evaluation of the elementary science program.

The teacher and administrator have the responsibility of weighing and coordinating the various evaluations of the elementary-science program. Children, teachers, and other members of the community all express their views about the program. To make a difference, however, evaluation must affect the program. To use evaluations to modify and improve programs is a task for the administrators, who are responsible for the development of programs of elementary science.

WHEN AND HOW SHOULD EVALUATION TAKE PLACE? If a program in elementary science is to be dynamic, if it is to make a difference in the lives of children, then that program must undergo careful and constant scrutiny. But, planning for the evaluative process must also be an integral part of the program in elementary science. This process

must not be left to chance, to be considered in a cursory manner every few years by a committee of teachers. Ongoing and thorough examination of a science program should be considered part of the educator's responsibility, and there should be adequate provision for meeting this responsibility.

A description of the procedure for involving responsible personnel in evaluating the program follows: In one local school a group of three teachers, one who taught five-, six-, and seven-year-olds, one who taught eight- and nine-year-olds, and one who taught ten- and eleven-year-olds, were the nucleus of a committee for the evaluation of the science program in each elementary school. These three teachers had the responsibility for gathering information from their co-workers each eight weeks. Such information was gathered verbally or in writing and included responses to the following questions: What content, methods, or materials have you used or would you like to use? Have you evidence that your present group of children is making use of previous experiences? Have you evidence that your children are strengthening their insights and expanding their interests in science? If so, what is making this possible? What improvements are you planning to make in your own science program? What improvements would you like to see made in our total school program in science?

Such information is invaluable in appraising a school's science program and as a basis for its improvement. With such information, committees of teachers and administrators can plan a series of meetings with the total teaching staff. Such meetings can lead to continuing improvement of the science program in the elementary school.

For such important curriculum work, leadership is needed to organize the evaluation and to find means to insure that the outcomes of the evaluative process are reflected in the developing program. Adequate periods of time must be planned for evaluation, and administrative and secretarial assistance should be provided to facilitate the work of the committees. The machinery must be set up so that representatives of various groups of teachers and administrators can work together on evaluation.

SOME CHARACTERISTICS OF A GOOD ELEMENTARY-SCIENCE PROGRAM. Each teacher, each elementary school, and each school system is responsible for determining the goals toward which science teaching and learning are directed. It follows that each teacher, school, and school system must be intimately involved in judging the appropriateness of the goals and the methods and materials employed in reaching those goals. Science programs will vary from community to community and certainly will change with the passage of time. It seems appropriate, however, to present the following characteristics of a good elementary science program, together with the criteria for evaluation in the hope that they will be of specific aid to educators in judging their programs.

*Characteristics of a Good
Elementary-Science Program*

Elementary science should be recognized as an important part of the total elementary-school curriculum. Science experiences should be a part of the total school experiences at each grade level. Elementary-school science should be an integral part of a K-12 science program.

A program in elementary science should be provided for *all* children.

The development of scientific attitudes is basic in a good elementary science program.

An elementary-science program should provide a balanced content in science.

*Criteria for Evaluating an
Elementary-Science Program*

Is sufficient time for science provided in the program? (Some educators are suggesting that one-fifth of the elementary program be devoted to science, one-fifth to social studies, one-fifth to language arts, one-fifth to expressive and graphic arts, and one-fifth to the development of skills related to learning.)

Has a curriculum in elementary science been developed for your school?

Do the science experiences at each grade level build upon experiences in previous grades and lead to experiences in subsequent grades? Is an administrator responsible for assisting teachers in developing the science program from the Kindergarten through Grade XII? Are parents regularly informed of the achievement of their child in science?

Do the teachers and administrators view science as important in the life of each child?

Realizing that all citizens must be aware of and understand the importance of science in a democracy, is a science program provided for all children?

Is opportunity provided to extend the horizons of those children who are especially fascinated with science?

Do teachers provide time for the exploration of ideas verbally and with materials?

Is there evidence that scientific attitudes are becoming a part of the behavior of children?

During each one- or two-year period, do children have an opportunity to explore in each of the several large areas of science, such as (a) our earth, its composition, and the changes occurring on it; (b) our earth in space; (c) the living things

*Characteristics of a Good
Elementary-Science Program*

*Criteria for Evaluating an
Elementary-Science Program*

Children need to have an opportunity to participate in a variety of activities in elementary science.

on the earth, how they grow, change, survive, and die; (d) the physical and chemical forces man uses; (e) man's place in his changing environment?

There is no one best way to develop elementary-science experiences. A good elementary-science program is characterized by a variety of challenging experiences.

Do children have a chance to participate in experiments, demonstrations, field trips, construction projects, library research, group discussions, and discussions with informed members of the community?

Is the curriculum flexible enough to provide time for investigating important science questions not provided for in the planned program in elementary science?

Adequate materials are provided to carry on a good elementary-science program.

Are appropriate manipulative materials provided as regular equipment in each classroom?

Is provision made for exploration of the out-of-the classroom environment?

Is each classroom provided with a science library of at least two different books per child?

Is there a selection of science books in the school library?

Are films, film strips, TV programs, slides, records of bird songs, etc., readily available?

Expert help is available to the classroom teacher, who is the key to a good elementary-science program.

Are professional books and curriculum materials in science provided for teachers?

Is some one administrator responsible for aiding teachers in the development of a program in elementary science?

*Characteristics of a Good
Elementary-Science Program**Criteria for Evaluating an
Elementary-Science Program*

Ongoing evaluation is a part of a good program in elementary science.

Is a consultant in elementary science available for each group of 18 to 24 classroom teachers in the school system to aid them in their work? Is this consultant trained both in working with elementary-school children and in science content?

Are opportunities available to classroom teachers for in-service education in science?

Is provision made for constant and thorough analysis of the elementary-science program?

Has the program in elementary science been improved substantially during the last two years?

These are some characteristics of good elementary-science programs. Committees of elementary-school teachers and administrators working in cooperation with teachers and administrators from other schools in the school system can use those characteristics to examine and evaluate their programs of elementary science. Such evaluations can lead to the continuing improvement of children's experiences in this important area of the total elementary-school program.

A SUGGESTED CHECKLIST FOR ASSESSING A SCIENCE PROGRAM*

U.S. Office of Education

This checklist, prepared by Specialists for Science at the U.S. Office of Education, is designed to help identify the strengths and weaknesses of a science program. The checklist can be used at all grade levels, in schools of different sizes, and by teachers of varying degrees of experience. Suggestions are offered on how to provide for broad participation in the evaluation of ten areas of the science program. A chart is provided for making an evaluation profile of these areas, to decide which science program problems are most pressing.

Many persons in all parts of the country are concerned about the quality of their schools. Taxpayers want to know whether their tax dollars are well spent. Administrators want to know what they can do to strengthen their school programs, and conscientious teachers and supervisors want to know how well they are doing in light of present efforts to improve teaching.

How to go about assessing a school program is a problem, particularly in science where content and methods are changing rapidly—perhaps even more so than in other subjects.

To evaluate a program some kind of yardstick is needed. This publication contains a suggested checklist that can help identify the strong points of a science program as well as those that need to be strengthened. The checklist may be used at all levels, in schools of varying sizes, and by teachers of varying degrees of experience. Therefore, the following suggestions on the use of the list are not all applicable to every situation. Many have come from individual teachers and supervisors and have been found useful by them; and there are, among the suggestions, some which will be of use to any school undertaking an evaluation of its science program.

This service bulletin has been prepared by the U.S. Office of Education at the request of many schools. This fifth revision, which results from extensive field use over the past several years, has been submitted to

* REPRINTED FROM *A Suggested Checklist for Assessing a Science Program*, U.S. Office of Education, Document OE-29034A, 1964, pp. 1-19.

competent specialists of science, professors of science education, science teachers, and others for comments and editorial suggestions. We wish to thank all who have had a part in making this checklist an improved instrument for the evaluation of a science program.

BROAD PARTICIPATION

The broader the participation of science teachers, supervisors, principals, and superintendents in the science program evaluation, the more satisfactory the results. To initiate it, each science teacher of a given school might fill out a copy of the suggested checklist. Then all the science teachers in each school of the district or system might, as a group (again using the checklist), evaluate their particular school's science program and prepare a composite checklist. Finally, the proper authorities could, in the same way, evaluate the science program of the entire school system. From the evaluations, a profile would emerge of the school system's strengths and weaknesses in science teaching. This profile would be the basis for setting up priorities in a plan to improve the science program.

RECENCY OF CONTENT AND METHODS

When using a checklist keep in mind the importance of *recency*. For example, a library collection in science cannot be considered up to date if few of the books, especially in rapidly developing science areas, have been published within the past 5 years. Similarly, a teacher's science background should be modern. Unless it has been updated by science refresher courses or independent study during the last few years, it too is out of date.

Teaching methods for science should be as modern as the content itself. It goes almost without saying these days that *how* children and young people learn is as important, really, as *what* they learn. Who would gainsay that they must be equipped to find answers to problems as well as to manipulate verbal and mathematical symbols in the three R's?

Merely to memorize facts is no longer considered sufficient in education. It has become increasingly clear that the apparent validity of a fact cannot be assured for any given length of time. But scientific methods of inquiry into the nature of things will stand the test of time and are as necessary in other areas of learning as they are in science.

In good science programs, pupils do not use the laboratory merely to confirm textbook statements or to follow step-by-step written procedures. Rather, they participate in activities that stimulate scientific creativity in identifying problems, stating hypotheses, designing experiments, and

evaluating data from many sources. Open-end activities, where the pupil can continue an individual investigation in greater depth, have been designed for both elementary and secondary grades; and reports concerning them have been published. In science many resourceful teachers use pupil-teacher planning to develop their own unique investigative experiments.

A PROFILE FOR DETERMINING PRIORITIES

Everything cannot be done at once—outline a science curriculum for junior high school, develop an inservice education program for elementary teachers, plan a program for academically talented senior high school students, provide individual laboratory work in general science, and arrange a science fair. Confronted by all these urgent problems, decide which ones in your own school are most crucial. How to decide?

One help in deciding might well come from making an evaluation profile from the data provided from this checklist of the science program. At the end of this publication is a suggested chart for such a profile which ties in with the immediately preceding suggested checklist. When the profile chart is filled in from the answers appearing on the checklists, it will become apparent which science-program problems are most crucial and pressing. These problems would naturally be given top priority and, as such, could then serve as the starting point to plan improvements in the program.

HOW TO USE THE CHECKLIST

The checklist items are merely suggestions. Many of the items are general statements because local school systems vary greatly. A school may want to revise them to fit local needs. In any case, it would want to examine each item—as it now stands or after revision—to make certain that when the entire list is applied to the local program it does in fact draw an accurate profile of that program.

More specific checklists will be required for followup use after this general checklist has been completed by the local schools. Such checklists will be available soon from the U.S. Office of Education for *elementary school science*, *junior high school science*, and *senior high school sciences* (biology, chemistry, and physics). These will search more intensively and more deeply into items which pertain especially to the levels mentioned above.

The checklist is provided with four answer columns, which may be used as suggested below, or the individual schools can write in their own headings, geared to local requirements.

Check (✓) the column most applicable:

3—There is *much* evidence that the practice exists

2—There is *some* evidence that the practice exists

1—There is *little* evidence that the practice exists

Insert O in column headed "other" if the item *does not exist*

Insert X in column headed "other" if the item *does not apply*

	3	2	1	other
1. (Item)				
2. (Item)				
3. (Item)				
etc.				

An alternate method of using the checklist is to place a check in one of the first three columns that answers the item as in 1, 2, or 3 below

3—Yes, there is *much* evidence that the practice exists

2—Yes, there is *some* evidence that the practice exists

1—No, there is no evidence that the practice exists

A SUGGESTED CHECKLIST FOR ASSESSING A SCIENCE PROGRAM¹

The items marked with an asterisk (*) may be considered as being of major importance or most desirable for a minimum basic science program. If a school wishes to change or add to these basic items, it may do so.

I. FOUNDATIONS FOR LOCAL PROGRAM PLANNING

	3	2	1	other
*1. Has a local science advisory committee been established?				
*2. Have such representatives of the local community as scientists, engineers, school and lay personnel been involved—to the extent of action—on the local advisory committee?				
3. Has a survey or a listing been made of local science-related resources available for improving science teaching?				
4. Have resources of local business and industry been utilized, e.g., field trips, classroom presentations, and science materials?				

¹ Adapted by permission. *School Management Magazine*, Inc., copyright 1959.

	3	2	1	other
5. Are scientists from the local area <i>regularly</i> invited to participate in the school's science program?				
6. Are scientists and science educators from nearby colleges and universities invited to serve as consultants and speakers for the school's science program?				
*7. Are measurements made of factors such as changes in enrollment and interest in science classes and activities which might be significant in planning for facilities, staff, budget, and curriculum?				
*8. Is there coordination to insure that conservation, health, safety, aerospace, and other like areas are being adequately included in the science program and at the same time are not being duplicated?				
*9. Is attention being given to coordinating the science program with the mathematics, English, social studies, and other programs?				
10. Is there provision for two-way communication between the community and school about changes in the science program, whether through the advisory committee or by some other means?				
11. Has an effort been made to develop adjunct science activities within the community, such as a junior museum, nature trail, or wildlife preserve?				

II. PUBLIC RESPONSIBILITY AND GOALS

- *1. Has the local board of education and the school administration evidenced a sensitivity for the responsibility for public education in science:
- By establishing policies which are consistent with local, State, and national needs, such as providing for an education adequate to give the background needed for future scientists, engineers, technicians, and scientifically oriented non-science citizens?

--	--	--	--

	3	2	1	other
b. By providing an opportunity for every child to study science at every grade level?				
c. By providing for the identification, encouragement, and development of boys and girls with special science talent?				
d. By considering the need for a science program for students with below-average ability?				
e. By recognizing that specific facilities and equipment as well as properly trained science teachers are a basic requisite to a good program, and by making plans to adequately finance such a program?				
*2 Have consistent long-range goals in harmony with the present American culture (as implied in the preceding statements) been established for your science program?				
*3 Do long-range goals give emphasis to the processes of scientific inquiry, e.g., problem recognition, assumption recognition, hypothesizing, observations as comparison and measurement, experimental design and conduct, data analysis and interpretation, and the extension and relating of understandings to new problems?				
4 Are the long-range goals for the science program used in determining short-range immediate objectives?				
5. Has competent outside professional guidance, both educational and scientific, been sought in the development of the long-range goals for your science program?				
6. Do the long-range goals consider the nature and importance of the history, philosophy, and lives of men of science as a major cultural influence?				
III. CURRICULUM				
*1 Does the content of science courses taught provide a valid impression of science as it				

	3	2	1	other
exists today both in terms of major ideas and the evidence upon which these ideas are based?				
*2 Have criteria, based on long range goals, been established for the selection and organization of course content?				
3 Are broad integrating themes used as the basis for developing an understanding of science?				
*4 Is science scheduled as a regular subject and is it available to each pupil at every grade level?				
*5 Is the amount of class time scheduled for science at every grade level sufficient for the full attainment of the desired goals?				
*6 Are open-ended and problem solving type activities used extensively as a means of developing:				
a. Scientific attitudes?				
b. Skills in the processes of scientific inquiry?				
c. Functional understandings of scientific concepts?				
*7 Do science courses provide frequent opportunities for each pupil to engage in laboratory work and other firsthand experiences?				
8 Are double laboratory periods or extended class time scheduled each week for the science courses offered in grades 7 to 12?				
9 Are the school's science laboratories and/or project work areas available to science talented pupils for independent projects and research outside of regular class time?				
10 Are the pupils who have shown interest in science careers provided opportunities to take at least 4 years each of science and mathematics in grades 9 to 12?				
11 Is every secondary school pupil required to take a minimum of 2 years of laboratory science, at least 1 each of biological and physical science, for graduation?				

3 2 1 other

*12. Does the curriculum at all grade levels give emphasis to the historical, biographical (men of science), and philosophical aspects of science?

13. Have the following been utilized in the development of science curriculum materials:

a. State department of education personnel?

b. Science supervisor?

c. Local teaching and administrative staff?

d. College and university scientists and science educators?

e. Business and industry personnel?

f. Representatives of lay organizations, e.g., county farm agents, health department, hospital, and clinic personnel?

14. Is there a trend in curriculum revision in your school to cover fewer topics (subject matter areas)? Are those areas that are selected for study covered in greater depth?

IV. TEACHING-LEARNING

*1. Are pupils at all levels given opportunities to:

a. Learn and practice skills in scientific observation?

b. Design, set up, and carry out controlled experiments to test hypotheses?

c. Formulate and delimit problems?

d. Recognize assumptions?

e. Prepare and discuss hypotheses regarding the solutions to problems?

f. Use appropriate instruments for making measurements?

g. Use proper statistical and mathematical procedures for handling measurements?

h. Evaluate and interpret evidence they have collected?

i. Learn the value of withholding judgment until sufficient evidence has been collected?

j. Recognize the nature of any conclusion and modify this conclusion on the basis of new evidence?

	3	2	1	other
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j. Recognize the nature of any conclusion and modify this conclusion on the basis of new evidence?				

3 2 1 other

- | | 3 | 2 | 1 | other |
|---|---|---|---|-------|
| *2. Do pupils at all levels have the opportunity to discover science principles through participation in experiences rather than through mere reading or talking about science? | | | | |
| *3. Does the laboratory work consist of working on real problems which are genuinely thought-provoking rather than performing "cookbook" types of exercises? | | | | |
| 4. Are teacher and pupil-teacher demonstrations used to promote critical thought and discussion rather than just to serve as illustrations of science principles? | | | | |
| *5. Are pupils encouraged to question evidence, challenge loose thinking, and develop hypotheses as an accepted part of classroom behavior? | | | | |
| 6. Do science activities seek to relate new learnings to previous learnings? | | | | |
| 7. Are pupils encouraged to develop investigations on their own? | | | | |

V. EVALUATION

Evaluation of Pupil Performance

- | | | | | |
|--|--|--|--|--|
| *1. Does the evaluation program make use of a variety of techniques and instruments such as the following: | | | | |
| a. Anecdotal records? | | | | |
| b. Performance tests? | | | | |
| c. Objective tests? | | | | |
| d. Essay examinations? | | | | |
| e. Observations of laboratory procedures? | | | | |
| f. Rating scales? | | | | |
| 2. Are inservice or other opportunities available for teachers to discuss and prepare evaluation materials and procedures? | | | | |

Evaluation of the Science Program

- | | | | | |
|--|--|--|--|--|
| *1. Are criteria for evaluation available which are based on the stated goals for the science program? | | | | |
|--|--|--|--|--|

3 2 1 other

2. Are materials (books, sample tests, and national norms) available within the school to help teachers evaluate pupil learnings in science?
- *3. Is there specific evidence that attempts are made at all grade levels to evaluate growth in the processes of scientific inquiry?
4. Are efforts made to follow up the graduates of high school to determine whether or not the science program has met the needs of:
 - a. Those who plan to follow careers in science?
 - b. Those who plan to become science teachers?
 - c. Those who plan to become science technicians?
 - d. Those who do not plan to pursue science-related careers but who will become scientifically literate citizens?
- *5. Are teachers encouraged and given the opportunity to evaluate their own teaching procedures?

VI. YOUTH ACTIVITIES

- *1. Does your school science program include one or more of the following:
 - a. Science clubs?
 - b. Science seminars?
 - c. Annual science exhibits?
 - d. Participation in a statewide or national organization?
 - e. Participation in the Junior Academy of Science?
 - f. The Westinghouse Science Talent Search?
2. Do the secondary school science pupils conduct research projects which may be exhibited at science fairs or science congresses?
3. Do pupils prepare and read scientific and research papers at science congresses, junior academies of science, and other scientific meetings?

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3 2 1 other

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|---|---|---|---|-------|
| *4. Do projects for science students emerge from and, in part, contribute to the on-going classroom activities? | | | | |
| 5. Are the science youth organizations affiliated with: | | | | |
| a. Local organizations? | | | | |
| b. State organizations? | | | | |
| c. National organizations? | | | | |
| 6. Are the faculty sponsors of science youth activities given either compensatory time or a salary supplement? | | | | |
| 7. Are science pupils encouraged to participate in: | | | | |
| a. Summer science camps? | | | | |
| b. Summer science institutes? | | | | |
| c. Summer science expeditions? | | | | |
| d. Summer employment in scientific laboratories? | | | | |

VII. STAFF

- | | | | | |
|---|--|--|--|--|
| *1. Are the NASDTEC-AAAS ² recommendations for preparation in science and mathematics met by a substantial portion of: | | | | |
| a. Elementary school teachers? | | | | |
| b. Junior high school science teachers? | | | | |
| c. Senior high school science teachers? | | | | |
| *2. Have all science teachers completed at least: | | | | |
| a. An undergraduate major in a science? | | | | |
| b. A master's degree in science? | | | | |
| 3. Are inservice institutes conducted for science teachers as a regular part of their professional workload? | | | | |

² *Guidelines for Science and Mathematics in the Preparation Program of Elementary School Teachers*, National Association of State Directors of Teacher Education and Certification in Cooperation with the American Association for the Advancement of Science, 1515 Massachusetts Avenue, NW., Washington, D.C., 1963.

Guidelines for Preparation Programs of Teachers of Secondary School Science and Mathematics, National Association of State Directors of Teacher Education and Certification in Cooperation with the American Association for the Advancement of Science, 1515 Massachusetts Avenue, NW., Washington, D.C., 1961.

3 2 1 other

- 10 Does the guidance staff include counselors who are sensitive to the needs of pupils interested in science?
- * 11 Do science teachers assume professional responsibility for career guidance of pupils interested in science?
- 12 Do science teachers work with other staff members to effectively coordinate teaching-learning activities.
- 13 Do science teachers assist pupils or refer them to appropriate personnel for assistance in the improvement of reading and study skills?

VIII. ADMINISTRATION

- * 1. Do the board of education and the administration have a policy to frequently review teacher assignments in terms of academic and other qualifications?
- * 2. Have the board of education and the school administration taken specific action to enable and encourage teachers to update their:
 - a. Professional qualifications?
 - b. Academic qualifications?
3. Are teachers on all grade levels encouraged to experiment with new content and techniques?
4. Are science teachers allowed time with pay to attend professional conferences related to the science program?
5. Does the school have a policy that provides for, encourages, and regulates:
 - a. Local field trips?
 - b. School journeys to special areas?
 - c. Summer excursions for scientific studies?
6. Does the administration exert leadership to encourage science teachers and other teachers to work together for overall science program planning as part of their regular assignment?

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3 2 1 other

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- [illegible]

THE EVALUATION OF ELEMENTARY SCIENCE

3 2 1 other

3. Are the following laboratory safeguards provided:
 - a. Prevention and control of gas, chemical, and electrical fires (blankets or extinguishers)?
 - b. Electrical equipment (fuses, breakers, etc.)?
 - c. Emergency shower and eye fountains?
 - d. "Hot lab" facilities for radioactive chemicals?
 - e. First aid kits or cabinets?
 - f. Properly placed exits?
4. Are the science facilities, furniture, and equipment suitable for and adaptable to:
 - a. Individual experimentation by pupils?
 - b. Long-term pupil experiments or projects?
 - c. Teacher and pupil demonstrations?
 - d. Small and large group work?
 - e. Effective use of supplementary aids?
 - f. Science clubs, fairs, and project activities?
5. Does each science teacher have facilities for effective performance of:
 - a. Preparatory activities?
 - b. Conference activities with pupils and parents?
 - c. The use of reference books and materials?
 - d. Desk and office functions?
6. Are adequate storage facilities provided in:
 - a. The rooms where science is taught?
 - b. Separate storage and/or preparation rooms?
7. Are equipment and supplies stored and organized for effective use in:
 - a. Classrooms and laboratories?
 - b. Storage facilities?
8. Are adequate inventory records and controls maintained for science equipment and materials?

[illegible]

	3	2	1	other
9. Are the science rooms equipped with the following instructional aids or are they readily available:				
a. Overhead projector?				
b. Microprojector?				
c. 16 mm. movie projector?				
d. Slide and filmstrip projector?				
e. Closed circuit television?				
f. Programed learning devices?				
*10. Are suitable ⁴ types of basic equipment and instructional aids provided and readily available to:				
a. Teachers for instructional purposes?				
b. Pupils for project work?				
c. Pupils for team work?				
d. Pupils for individual work, both during and outside of classroom time?				
*11. Are adequate ⁵ quantities provided of the following:				
a. Textbooks with recent copyright dates?				
b. Science periodicals for teachers?				
c. Science periodicals for pupils?				
d. Science reference books for teachers?				
e. Science reference books for pupils?				
f. Professional science journals?				
12. Are the following types of facilities available in areas where possible:				
a. A school pond or wild life area?				
b. An area where activities related to conservation may be carried out?				
c. A greenhouse?				
d. A weather station?				
e. A planetarium?				
f. An area where the environmental conditions—temperature, light, and moisture—can be controlled and varied?				
*13. Is the library adequately equipped with books for a comprehensive science program?				

⁴ Should be interpreted as meaning sufficient for the full realization of the purposes and goals of the course.

⁵ *Ibid.*

14. Does the science staff request additional titles to supplement existing references?

15. Is the library effectively and regularly used by the:

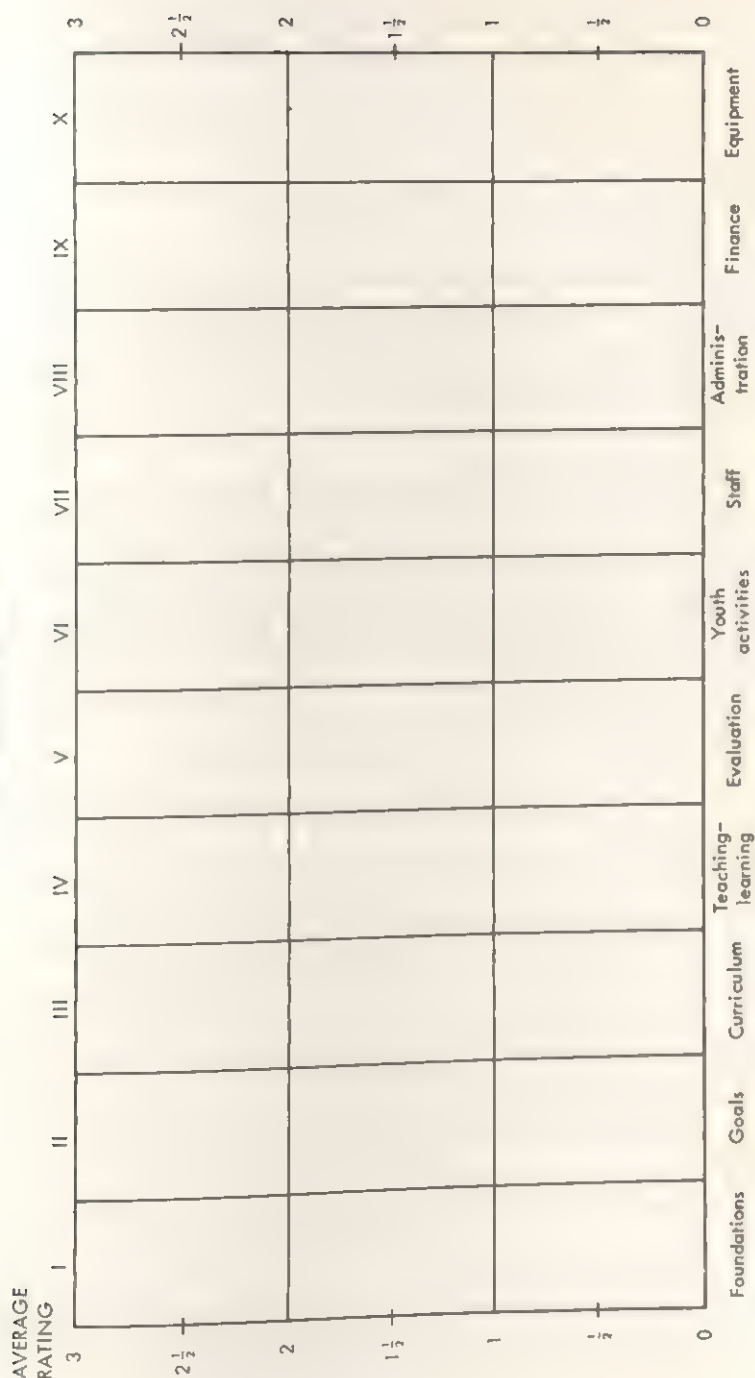
a. Pupils?

b. Science teachers?

3 2 1 other

	3	2	1	other
14.				
15.				
a.				
b.				

EVALUATION PROFILE



HAS THE OBJECTIVE BEEN ATTAINED?*

Ronald D. Anderson

Ronald D. Anderson cites the three main reasons for evaluation, namely, (1) to find out how well the child is learning, (2) to find out how well the teacher is teaching, and (3) to report the child's progress to his parents. Dr. Anderson focuses his attention on the first two reasons, and discusses formal and informal evaluation techniques. He cautions teachers to be sure that all the objectives are given proper attention and that the measurement planned does actually measure the stated objectives.

Broad general objectives are important to give general guidelines, but if they are to serve as an adequate basis for planning either teaching or evaluation, they must be translated into specific objectives for each day. In fact, if specific objectives for the day are formed, a great deal of the planning for the teaching and evaluation already has been done. The evaluation, in particular, is aided by stating as part of an objective, the conditions under which the behavior is expected and the minimum acceptable level of performance.

REASONS FOR EVALUATION

The most important reason for conducting careful evaluation of the science program is to locate learning difficulties that individual children are encountering and aid them in overcoming these difficulties. To accomplish this purpose, the evaluation must be a continuous activity that is done each day and not put aside until the end of a unit when a formal evaluation is made. It may be difficult in a large classroom, but the teacher must continually attempt to determine what obstacles, if any, each child is encountering.

A second important reason for careful evaluation is to enable the teacher to change and alter her teaching practices and procedures in the manner that will best improve the learning situation. The idea that appeared promising before trying it in the classroom may, in practice, be a complete failure in terms of the objective it was expected to accomplish.

* REPRINTED FROM *Science and Children*, Vol. 5, No. 2, October 1967 pp. 33-36. Copyright, 1967, by the National Science Teachers Association, Washington, D.C. Reprinted by permission of the author and the publisher. Dr. Anderson is Associate Professor of Education at the University of Colorado.

Or possibly the objective itself is unreasonable when viewed with respect to the classroom experience. An evaluation at the end of the unit should show if the promising idea "fizzled." Here again, the continuous day-to-day evaluation of the teaching techniques is important so that revisions can take place.

A third reason for evaluation is as a base for reporting a child's progress to his parents and other members of the school staff who work with him. Usually this is referred to as grading, although the report may include more than just a grade. Grading or reporting of student progress is a matter of importance but is not our major concern. Even though it is one of the reasons for evaluation in elementary school science, the focus of this article is on the evaluation itself.

TYPES OF EVALUATION

It might be helpful to discuss two types of evaluation which can be referred to as informal and formal. Formal evaluation refers to paper and pencil tests, or other devices such as individual tasks which are administered uniformly to all the children in the class. This type of evaluation will be discussed in detail in the following sections. Much of a teacher's evaluation is more informal and is based upon her observations while the usual classroom activities are underway. The responses that children make to the teacher's questions and the questions that children ask are noted by the perceptive teacher. In addition to verbal statements and questions, the actions of children as they work with equipment provide important information for informal evaluation.

It is important that the teacher's informal evaluation be centered on those behaviors which are her objectives and that she not be unduly influenced by unrelated behaviors of the children. If one of the objectives for the day's work is that children be able to formulate hypotheses concerning a particular phenomenon, such as the breaking of rocks during freezing weather, the teacher should be listening for statements that indicate that a hypothesis has been suggested. The central objective is for the children to develop their ability to formulate hypotheses. The behavior that is indicative of this should be of major concern to the teacher rather than verbal fluency or discussion of the breaking of rocks in freezing weather which is unrelated to hypotheses concerning the phenomenon.

Informal evaluation of the type described above is dependent upon a certain type of teaching. The teacher who does not have much student involvement (for example, the discussion of thought-provoking questions), often is not in a position to observe student behaviors which are indicative of whether or not an objective has been reached. This indicates clearly the close "tie-in" between objectives, teaching, and evaluation. Ample evidence is available to show that student involvement is important for

science teaching, particularly for objectives related to the processes of science. This student involvement also is important for the informal evaluation in which a teacher evaluates on the basis of what students *DO* on a day-to-day basis. What is good teaching practice also is generally advantageous for evaluation.

COVER ALL OBJECTIVES

The more formal evaluations such as paper and pencil tests should be planned carefully to insure that all objectives are given proper attention and that the measurement planned actually does measure the stated objectives. The first step, specifying the objectives, was discussed in the first article. It is well to remember, however, that teaching is a very dynamic and flexible activity, and as a result of interaction with the children, the objectives may have been altered or given a different emphasis. Now that preparations are being made for the evaluation, it is time to consider again exactly what goals *have* been sought.

The next step is to weight the various objectives according to the relative emphasis given to them during the teaching. For example, if two days were spent on the measurement of temperature and one day on formulating hypotheses concerning the change of state of water from one form to the other, the former should receive twice as much emphasis in the evaluation. If it is a paper and pencil test, the number of items or questions should be in proportion to the time spent on the objectives which they are designed to measure.

A crucial step is the selection of the evaluation technique which will be used to measure the various objectives. The technique used is dependent upon the nature of the objective. Many teachers use a particular type, e.g. an objective paper and pencil test, regardless of their objectives. Sometimes a particular evaluation technique is appropriate; many times it is not. This teacher then asks herself, "What are some items that are related to the topics that have been considered?" There are at least two things wrong with this approach. First, the achievement of the objective at hand may not be measurable with this technique. Second, just because the test items chosen are on the same topic as the objectives, does not insure that the items actually measure the students' achievement of the specific objectives.

The first type of error is shown by the following example. One of the objectives for a unit is that children should be able to classify a group of leaves into three groups on the bases of color, size, or shape. Paper and pencil items are probably not the most appropriate means of evaluating whether or not this objective has been achieved. In this case, each child could be given a group of leaves and asked to classify them. It may be possible to devise paper and pencil items using pictures that test such an ability, but a teacher is more likely to devise a means of measuring the

stated objectives by the above technique than by objective test items which she devises.

The second type of error is shown by a teacher's evaluation of the following objective: Given data showing the daily fluctuations in temperature over a two-week period, the child should be able to construct a graph which shows the relationship between time and temperature. In this case the teacher constructed this true-false item which referred to a graph of time vs. temperature: The graph above shows the relationship between time and temperature. This item was on the same topic as the objective, yet it was not a measure of the students' achievement of the objective. The item required that the student be able to determine what had been plotted on the graph, but the objective stated that the child should be able to construct a graph. In this case, it would have been more appropriate to give the student some data and ask him to construct a graph.

VARIETY OF FORMAL EVALUATION TECHNIQUES

Two main types of formal evaluation techniques have been referred to thus far—paper and pencil tests and the systematic use of situations in which individual children are presented a situation which includes the use of material objects. The latter type is used very extensively in the evaluation program of *Science—A Process Approach*.¹ Each child is individually presented with a standard situation and given specific directions for indicating his responses on a check sheet. Some of their items and the objectives they were designed to assess will serve as good examples of this evaluation technique.

One of the objectives for a lesson on color in Book One is that the child should be able to "identify the following colors by sight: yellow, orange, red, purple, blue, and green."² A competency measure designed to assess the achievement of this objective has the following directions:

Show the child each of three blocks—a yellow (1), a red (2), and a blue (3) one, and say to the child, WHAT IS THE COLOR OF THIS BLOCK? Repeat for all three blocks. One check should be given in the acceptable column for each correct name.³

In Book Four is a lesson on communicating entitled "Describing an Experiment." The objectives of this lesson are:

The child should be able to describe any one of the following portions of an experiment which he has just observed or conducted:

1. the question to be answered.

¹ Commission on Science Education, *Science—A Process Approach*, American Association for the Advancement of Science, Washington, D.C. 1965 and 1966.

² *Ibid.*, Book One, p. 1.

³ *Ibid.*, Competency Measures, Parts One and Two, p. 11.

2. the method or approach used.
3. the apparatus and procedures used.
4. the results obtained, as observed.
5. the answer to the original question.⁴

The competency measure designed to assess the achievement of this objective is as follows:

Tell the child: I AM GOING TO EXPERIMENT TO SEE WHAT HAPPENS TO A PENCIL FLOATING IN WATER WHEN SALT IS ADDED TO THE WATER. I WANT YOU TO WATCH ME CAREFULLY SO THAT YOU WILL BE ABLE TO DESCRIBE WHAT I DID. Fill the test tube with water and place a pencil in the tube. Place test tube next to a ruler and record the reading either at the bottom or the top of the pencil. Pour salt (two tablespoons) into the test tube and record the reading again. (Change in level will be about one half centimeter.) Ask the child. WRITE DOWN OR TELL ME IN WORDS ALL THAT YOU CAN ABOUT THIS EXPERIMENT. Give him one check for each of the following steps that he includes:

1. question to be answered.
2. proposed method or approach.
3. apparatus and procedures required.
4. results obtained, as observed.
5. answer to the original question.⁵

Note some characteristics of these examples. In contrast to informal evaluation, this is a carefully defined standard situation which is the same for each child. There is a close correlation between the stated objectives and the items used for evaluation. It is apparent that the evaluation items were designed specifically to measure the corresponding stated objective. Also, these items are not dependent upon either the child's reading or writing ability. In both cases the child does not read anything. In the second example the child may write his answer but only if he prefers this method to telling the teacher his answer.

An obvious difficulty with this type of evaluation is the time required to administer the assessment to each child in the class individually. On the other hand, its freedom from dependence on writing and reading ability gives it an advantage over paper and pencil tests. The reading difficulty of paper and pencil tests is a major problem when employing them at the elementary school level. Both varieties of assessment devices have their advantages and disadvantages. In choosing between them the basic question should be, "What can I use that will determine if my objective has been attained?" As a result, an assessment of the student's achievement over a fairly long period of time will probably include some of both types.

The situation evaluation technique, with some modifications, can be

⁴ *Ibid.*, Book Four, p. 95.

⁵ *Ibid.*, *Competency Measures*, Parts Three and Four, p. 85.

used with groups of children rather than individuals. When used with groups, the children generally are required to give their responses on paper rather than verbally. This is a useful form of evaluation in that it combines the flexibility of the situation technique with the efficiency of paper and pencil tests. Because of these dual advantages, some teachers find this technique to be the most useful of all the evaluation techniques which they employ.

The higher the grade level, the more paper and pencil tests are likely to be employed. This is understandable, since as the child's reading and writing abilities increase, the better able he is to respond to this kind of examination. At present it is the most widely used type of evaluation for elementary school science. Since science is being tested, every effort should be made to reduce the influence of the child's reading ability upon his score. This influence is greater than most teachers realize. One helpful procedure is to project the test on a screen with an overhead projector and read each item to the children as they respond to the questions on their own copy of the test. With the modern equipment which many schools have today it is relatively easy to make an overhead projector transparency of any printed material.

The construction of good essay, matching, true-false, completion or multiple choice items is not a simple matter. An adequate discussion of this topic would require far more space than is available here. For helpful information on the construction of good items, the reader is referred to one of the many good books in this area such as those written by Stanley⁶ or Ebel.⁷ If the reader is not thoroughly familiar with the principles of constructing good test items, he should spend time studying the relevant chapter or chapters of such a book.

In summary, the key to good evaluation is carefully defining objectives and then devising a means of determining if the objectives have been achieved through informal and formal evaluation.

⁶ Stanley, Julian C., *Measurement in Today's Schools*, Fourth Edition, Prentice-Hall Inc., Englewood Cliffs, N.J. 1964.

⁷ Ebel, Robert L., *Measuring Educational Achievement*, Prentice-Hall, Inc., Englewood Cliffs, N.J. 1965.

EVALUATION IN ELEMENTARY SCIENCE BY CLASSROOM TEACHERS AND THEIR SUPERVISORS*

Harold E. Tannenbaum, Nathan Stillman, and Albert Piltz

This article is intended by the authors to serve a number of different purposes in the area of elementary school science. First, it should be helpful to supervisors and administrators on the state and local levels in evaluating the effectiveness of the elementary science program. Second, it should enable teachers to do a more effective job of evaluating the growth of their students in achieving the goals of the science program. Third, it should provide supervisors with material for in-service teacher education programs in evaluation. Fourth, it should aid supervisors by giving them guiding principles for measuring the effectiveness of teachers. This article is an excerpt from the U. S. Office of Education Bulletin Evaluation in Elementary School Science.

"What," "how," and "how well" are key words introducing three of the major questions faced by every supervisor and classroom teacher in the formal education of students. The first, "What should children learn?" is concerned with both the long-term goals and the consequent immediate objectives of the educational enterprise. The second, "How should they learn?" related to the problem of method or of determining the most effective means of helping students achieve the objectives. The third, "How well have they learned?" involves ascertaining the degree to which the objectives have been achieved. It is this careful appraisal of where a pupil is and how well he is progressing that comprises "student evaluation."

Teachers generally and rightly consider evaluation as one of the most complex problems in teaching and one for which they have been inadequately prepared. This is especially true in the area of elementary school science, where curriculums are undergoing extensive revisions not only in relation to content but also with respect to scientific attitudes and problem solving approaches. Standardized tests in elementary school

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science which would be appropriate for most schools are still nonexistent. Merely using a test labeled "science" could well result only in obtaining erroneous information about students and would be worse than not using tests at all. Thus, both the classroom teacher and the local personnel charged with the supervision of the elementary school science program are faced with the responsibility for learning how to develop, use, and interpret a variety of appraisal techniques for the purpose of furthering the teaching-learning process.

Measuring the outcomes of the teaching-learning process requires a great variety of evaluative techniques. For some purposes, testing devices such as objective tests or essay tests are not only satisfactory but even necessary. For example, objective tests can be used to determine if students can define such terms as "compound," "mixture," and "element"; essay tests can be used to determine if students are able to use these terms in formulating chemical explanations of natural or man-made phenomena.

Other kinds of achievement can be evaluated by nontesting techniques such as the rating of pupil-made products, or observation of a pupil's classroom performance, or the nature and extent of an individual child's behavior during selected science activities. Consider science fairs and the children's exhibits as an example. In addition to being excellent motivators, such activities can furnish the supervisor and teacher with many opportunities for evaluating how well given pupils are progressing towards pertinent goals of the science curriculum. Does the exhibit present scientific information clearly? Are the details of the exhibit relevant to the main concept? Can the student explain his exhibit so that it is obvious that he understands the principles involved? Such nontesting techniques are valuable in judging the progress of students and the effectiveness of programs.

Dependable evaluation is recognized as fundamental to both effective teaching and effective learning. Thus, evaluation procedures used by a teacher with his class can serve such functions as:

1. Providing feedback information for the teacher and helping him decide how effective a given amount of teaching has been.
2. Supplying diagnostic information concerning individual pupils.
3. Providing motivation for students. As pupils see progress toward established goals, they can be motivated to further learning.
4. Affording sound evidence for differentiating among pupils.

1. Defining Objectives

The first and most important step in evaluating teaching and learning is to define the objectives that are to be attained, and questions like the following may prove useful:

- a. What problem-solving abilities is the student expected to achieve? Can

he describe what he saw when he watched a candle being snuffed as a jar covered it? Can he formulate hypotheses about the observed phenomena? Can he plan experiments to test his hypotheses?

b. What information is the student expected to acquire? Has he learned the components of air? Does he know about changes in percentages of these components depending upon altitude or other variables?

c. What skills is he supposed to display? Can he measure amounts of air that are consumed by a candle burned in a jar? Can he manipulate science equipment so that he can perform experiments with air?

d. How is he expected to reveal his attitudes? Does he defer judgment when he observes a demonstration? Does he consider the reliability of a source of information?

e. What applications of his knowledge is the student expected to make? Can he apply what he learned about candles burning in a jar to other problems involving combustion? Does he understand that rusting of iron is another form of oxidation?

All school programs have objectives, but too often these are stated in very general terms and are vague and unclear. Before a supervisor or teacher can determine whether a student has reached certain objectives, he must be able to identify specifically what the student was supposed to achieve. For example, "to help students develop a wholesome attitude toward science" or "to help students appreciate the methods of science" are purposes that have little meaning and would not be useful as guides for evaluation. Objectives must be clearly and specifically defined in terms of pupil behavior, and the performance expected of a student if the objective has been achieved must be specified. If a teacher is unable to list the characteristic behaviors of a student who has reached a particular objective, it is meaningless.

The job of defining objectives in terms of student behavior is recognized as an extremely difficult one, but it is basic to effective evaluation. For example, consider the long-term goal "to help children learn some techniques of problem-solving." Among the specific pupil behaviors that might be expected when this goal is achieved are the abilities to:

1. State a variety of hypotheses concerning the problem,
2. Plan experiments for testing these hypotheses,
3. Report observed phenomena, and
4. Generalize from what has been observed.

As a second example, the long-term science goal "to help children develop rational attitudes toward the world around them" may be cited. When this is specified in terms of pupil behavior, it might require that the child be able:

1. To identify certain superstitions, and
2. To identify sources of information and consider their dependability.

In every science unit, certain of the attitudes, skills, and techniques that have been defined generally must be spelled out so that they relate to the science to be taught. Thus, in a study of weather, growing out of the goal of identifying superstitions might be the following immediate objectives. The pupil can:

1. Distinguish between "weather superstitions" and "weather facts," and
2. Offer explanations for the origins of some "weather superstitions."

In a similar manner, the goal of identifying sources of information and considering their dependability might be formulated as the following objective. The pupil can:

Compare the reliability of weather information from such varied sources as the United States Weather Bureau and the *Farmer's Almanac*.

The examples cited above suggest only a few of the kinds of behavior which would indicate achievement of the desired goals. There are, in every case, many different kinds of behavior which could be examined. In fact, there are far too many behavioral characteristics for adequate consideration by teachers in elementary school classrooms, and some of the desired behaviors, while very important, do not lend themselves to evaluation in classroom situations. What the teacher must do is to choose those particular behavior patterns which he feels are important and measurable within the framework of his classroom, and use them as his criteria for evaluation.

2. Assigning Relative Emphasis to Objectives

Every unit in elementary school science has a variety of objectives which students are expected to attain. However, all of the objectives are not of equal importance. If an objective has been assigned major emphasis, it should be allotted a greater proportion of the class time; other objectives, which have been assigned lesser emphasis, should be allotted relatively smaller amounts of time. Therefore, to simplify the process of planning a unit of study, the weight assigned to each objective should be specified. This can be easily accomplished by using the numerical scale of 100 and distributing numerical weights to each objective. Higher weights should be assigned to major objectives and lower weights to minor objectives. If the objectives are all determined to be of equal importance, equal weight should be assigned to each.

This simple system of assigning weights to objectives has real value for the teacher in planning both the content and the evaluation. He now has a measure for determining how much class time should be allotted to the achievement of each objective, as well as an index of the degree to which the objective should be emphasized in the evaluation process. For

example, if major emphasis is placed on helping students learn to use the microscope, this should be emphasized to a similar extent in the total evaluation of the student's achievement. If identifying the parts of the microscope is considered a minor objective, it should receive relatively little emphasis in the appraisal process.

The procedure of assigning weights to objectives does not have to follow a rigid formula but may be as flexible as a teacher desires. The emphasis allotted in a classroom quiz may differ from the emphasis assigned in a weekly test. In addition, the distribution of emphasis may be modified from group to group, depending on such factors as the students' readiness for achieving certain objectives, their current interests, and the availability of necessary materials and equipment for developing particular areas of the elementary science program. But regardless of what evaluation procedure is used, the important factor is that the procedure be planned so that it achieves the purpose for which it was intended.

3. Outlining the Content

Once the objectives have been clearly specified and defined, the next important step in the evaluation process is outlining the content. The content of the unit or area of study becomes the actual means of achieving the objectives. The term "curriculum" frequently is defined as a means to behavioral ends. The content of a unit is the curriculum for attaining the specific behavioral objectives of that unit. By outlining the content, the teacher is able to relate the particular objective to the method of achieving the objective. Frequently, the same content can be utilized in attaining several objectives; sometimes a variety of methods have to be developed for achieving a single objective. For example, if an objective of a science unit is to help children learn to use measuring instruments such as thermometers, the content might include activities like reading daily temperatures in and outside of the classroom, measuring temperatures in sun and shade, or measuring temperatures of hot and cold liquids. This content also could be used for achieving other objectives relating to heat absorption, heat reflection, heat transfer, or insulation.

Another way in which outlining the content can have value for the teacher is in predetermining the specific materials and equipment which must be available for achieving certain objectives. If children are to use thermometers, such instruments must be available in sufficient quantity so that each child may have several opportunities for using the instrument. If skill in doing reference work about geologic periods is in the objective, a variety of appropriate books on historical geology must be available so that each child may read from various sources and compare the information obtained.

Although this may appear to be a time-consuming task for the teacher, it actually can simplify the arduous job of preparing conventional lesson plans and, in addition, specify the evaluation procedure to be used in determining student progress toward particular objectives. A simple way of arranging objectives, content, and evaluation for a unit is to use a three-column table. The first column would contain the objectives; the second column would indicate the methods and materials necessary for achieving each objective; and the third column would specify the type of evaluation procedure to be used in determining student achievement of each objective.

In the first table one objective requires two procedures for evaluation:

<i>Objective</i>	<i>Methods and Materials</i>	<i>Type of Evaluation</i>
The ability to record and interpret temperature data from information gathered using outdoor thermometers	Make simple bar graphs of the daily temperature as found at noon in the shade next to the building.	Examine the charts prepared by each child. Does the chart show that the child can make an accurate and understandable table of data.
	Use the graphs to find significant temperature information; make comparisons among the days studied and also among reading made by different children.	Devise written questions to be answered by individual children, each using his own chart: Which day was hottest? Which day was coldest?
	Have sufficient supply of outdoor thermometers so that variations in readings can be observed.	On which two days was the temperature about the same at noon.
	Have necessary graph grids prepared so that each child has appropriate equipment.	

In the second table, two objectives may be evaluated through a single procedure:

<i>Objective</i>	<i>Methods and Materials</i>	<i>Type of Evaluation</i>
The ability to use library resources to do reference work	Introduce the use of the card catalog and encyclopedias, to show a) How to search out appropriate references; b) How to make summaries; c) How to make a bibliography.	Examine the summaries for accuracy of reporting, comparison of material found in different sources, completeness of bibliography, comprehension of content.
The ability to prepare a summary of information found on the last glacial period in North America	Have each child find at least four appropriate references. Make sure there are sufficient references for the children's use. Make sure there are reading materials at the appropriate reading level for each of the children.	

EVALUATION TECHNIQUES

The teacher who is concerned with evaluation will recognize that he must select appropriate evaluation methods for each of his educational objectives. For certain objectives, the overt behavior of the student—in the classroom situation, in the library, in the laboratory—would yield the most appropriate information. For other objectives, where opportunities for students to demonstrate their actual behavior are very limited or do not exist, pencil-and-paper tests would be more satisfactory. Some objectives are more difficult to measure than are others; for some, appropriate measuring devices have not yet been developed. However, because of the intimate relationship which exists between the objectives and evaluation, objectives must be stated in concrete and specific ways if evaluative results are to lend themselves to precise statements; objectives that are stated in vague and general terms result in evaluation methods that yield incomplete and inaccurate results.

The various kinds of evaluation—observation of student behavior, appraisal of student projects, and the variety of paper-and-pencil tests—yield a wide range of information. But unless sufficient use is made

of the results of such observations, appraisals, and measurements, they become a waste of time both for the supervisor or teacher and for students. Such evaluative techniques have three basic uses. In the first place, they can provide a means for assessing the growth of individual students. Secondly, such devices can help each student know his strengths and weaknesses. Finally, through the use of these techniques, a supervisor or teacher can learn how well the objectives of a program are being met.

It must be remembered, however, that the supervisor or teacher is the ultimate evaluator. A test or other evaluative device can gather information about a student or a program. But only the evaluator can look at this information, weight it, add and subtract related data, and come up with an appraisal of where a student is in relation to his potential, or how well a program is attaining its stated objectives.

1: Selection of Appropriate Devices

There is no single evaluation procedure which is best for judging student achievement. Each method has its advantages and limitations, depending on the situation in which it is used. The key to selecting the most appropriate technique is the behavioral objective the teacher wishes to measure. How should a teacher appraise a child's ability to work cooperatively with others on a science problem? A written test for this kind of appraisal would be pointless. Observation of the students in a variety of classroom situations would seem more appropriate in determining progress toward this objective, but even "observation" had its limitations and must not be counted on for evaluating too many objectives. Two criteria for the effectiveness of observation as an evaluative technique are suggested:

1. Can the desired behavior be evoked in the classroom?
2. Has the teacher sufficient opportunity to observe and record what he sees?

Take another example: How should skill in setting up laboratory apparatus be measured? Often, teachers wishing to make such a determination give a written test and make their evaluations on the basis of such test results. A moment's consideration, however, shows that such tests are nowhere near as appropriate as having the student actually carry out the desired laboratory procedure. In fact, it is quite conceivable that students could answer correctly all the questions relating to the ways in which a Bunsen burner should be lit, but, placed in the actual laboratory situation, be unable to light the burner correctly and safely. Again, the kind of test that is given must be determined by the kind of behavior to be observed and evaluated.

Under what conditions, then, are pencil-and-paper tests appropriate? What can such tests indicate? If the teacher is concerned with determining

how well students can explain certain phenomena, compare materials from several sources, make inferences, draw conclusions, or select significant factors, pencil-and-paper tests are appropriate vehicles.

It is also necessary to recognize that for measuring certain desired outcomes present devices for evaluating student behavior are still inadequate. Results of attempts to evaluate such behaviors are highly unreliable and must be treated with this fact in mind. One such behavior pattern relates to the use of science information in the choice of a well-balanced diet. Obviously, young children are not in a position to purchase and prepare their own meals. Thus, the desired behavioral objective cannot be measured adequately at this time. In short, each teacher must recognize what he is trying to measure and to what extent his measuring device is effective.

2. Validity and Reliability of Evaluation Techniques

There are two important factors that teachers must consider before using any procedure or instrument for determining student growth. The first and foremost factor is validity, the second is reliability. An instrument is valid insofar as it measures what it is supposed to measure. An instrument is reliable insofar as it measures accurately. A thermometer can be perfectly reliable in that it measures temperature accurately, but the thermometer alone hardly would yield valid results in measuring the caloric content of a substance.

The distinction between reliability and validity can be seen clearly when one examines the stated objectives of a given science program and then considers almost any of the currently available achievement tests in elementary school science. The tests all report high reliability. In general, these reports are true; the tests do measure accurately what they set out to measure. But an inspection of the content of these tests and a comparison of the items in the test to the stated objectives of a particular science class readily show that there is little relationship between the items found in the test and the objectives for which elementary science is being taught. Actually, the validity of these tests for measuring what is being taught in science classes is extremely low. The ideal evaluation technique must serve the purposes for which it is intended and it must yield information that is accurate.

Since validity is so important in evaluation, teachers must be very much concerned with this factor both in selecting commercial testing instruments for measuring the work of the students in their classes and in preparing their own instruments. The validity of any teacher-made instrument will depend on the degree of correspondence between the behavior that is to be appraised and the objectives that have been set for given instruction. It is for this reason that so much emphasis has been placed on identifying the behavioral objectives as the first step in the evaluation process. If the teacher can spell out the way in which a student

will act after he has learned a given item or successfully mastered a given unit of work, he can then construct valid evaluative instruments by developing situations in which the student will be able to indicate how effectively he has mastered the desired behavior. For example, if it is desired that a student know the parts of an electric motor, a pencil-and-paper test which requires the student to describe these parts could be satisfactory.

However, suppose the stated objective of a unit is to develop an understanding of the interrelationships of the parts of an electric motor. A test which asks students only to identify or describe the parts of the motor would not be valid in relation to the stated objective. Some kind of test situation which determined the extent to which the student understood the interrelationships among the parts would be necessary. A valid test might ask the student to explain the relationship of the armature to the brushes. Or he might be asked to explain the relationship between the stator and the rotor. For the test situation to be valid, it must elicit responses that are very similar or identical to the objectives of the unit being studied.

Another important factor which teachers should be aware of both in selecting and in making valid instruments is the vocabulary used for the test situation. If a test or an item in a test is worded so that it can be understood by only a few students in the class, such an item is not valid for measuring the learning outcomes of the other members of the class. This is especially true in the primary grades, but also holds true for other groups in which there are wide variations in reading ability and comprehension.

Reliability of commercially prepared testing materials is generally not a problem. Such materials usually are carefully designed and controlled for reliability. But the reliability of teacher-made classroom tests depends upon a few special considerations. The usual and conventional methods of developing reliable tests of the standardized variety generally are impractical for teacher-made tests. However, since the major reasons for the low reliability of teacher-made tests are that such tests are either too short or too difficult, remedies can be found which will help teachers prepare more reliable tests.

First, teachers should include large numbers of items in the test; second, each test should include an adequate number of items which most students will be able to answer. For example, if a test is to be constructed to determine the ability of students to classify foods as proteins, carbohydrates, or fats, listing merely three foods—nuts, dried beans, and apples—would make a test that has little reliability and, incidentally, little validity. To improve the reliability of the test, large numbers of foods of each of the three categories would need to be included. Furthermore, among the items included would need to be simpler ones such as meat, butter, and sugar. Adequate samplings must be included if an evaluation device is to have high reliability and high validity.

Finally, adequate samplings are needed so that the teacher can determine how well—to what extent—a student is meeting the objectives which have been established for him and for the class as a whole. It is the student's performance on the samples included in a test that enables the teacher to judge the student's progress in the total area which has been studied. To obtain sound results for such evaluations, test samples must be sufficiently large and sufficiently varied in difficulty.

CATEGORIES OF CLASSROOM TESTS

The classroom test is still the foundation of the day-to-day evaluation program of most schools. Yet many of these tests have poorly framed items confusing directions, ambiguous statements, and other flaws that seriously impair the usefulness of the scores they yield. Some of the basic principles of test construction are summarized below so that teachers will be able to derive full value from the use of these instruments in evaluating student growth.

Classroom tests generally are classified into two broad categories, essay tests and objective tests. The essay or free-response examination permits the student to compose and express his answer in his own words. The response may range from a few sentences to several pages, and the accuracy and quality of the response is judged subjectively by a person who is competent in the field.

Objective tests restrict the student's response to a symbol, word, or phrase, and subjective judgment is practically eliminated in determining the accuracy of the answer. The term "objective" as applied to objective tests refers to the scoring of the response and not to the choice of the content. Objective-test items generally are classified as supply or selection items. In responding to a supply item, the student provides the necessary word, phrase, or symbol. In responding to a selection item, the student chooses a response from among those presented to him.

1. Essay Tests

Essay tests have certain advantages that cannot be matched by any other form of evaluation. The chief merit of the essay item is that it provides the student with an opportunity to demonstrate the degree to which he can analyze a problem, select relevant information, present evidence, and organize his answers logically and effectively. In addition, since no answer need be completely right or completely wrong, it is possible for a teacher to determine the degree of correctness of a student's response.

Despite these distinct advantages, essay tests have come under considerable attack in recent years because of certain glaring weaknesses. Many essay tests, as they are currently used in various schools, measure nothing more than the ability to reproduce information. Merely phrasing a

question in essay form does not automatically guarantee that progress toward such goals as recognizing causal relationships, applying principles, or making generalizations will be assessed. In addition to poor design of questions, the essay test frequently suffers from inadequate sampling, from highly subjective and inconsistent scoring, and from the influence of such extraneous and irrelevant factors as literary skill and handwriting. However, these are weaknesses that can be overcome, and the following guidelines are suggested to help teachers develop greater skill in designing appropriate items and in improving their methods of evaluating student answers.

a. Limit the use of essay items to those objectives that are measured most efficiently by the essay format. For example, the question:

What is the accepted composition of air at sea level? tests only for specific facts, namely, the percentages of various components of air. It illustrates inefficient use of an essay item. The essay item should be reserved for evaluating progress toward more complex educational goals than merely reproducing information. The following example, based on the same general topic, is more appropriate for an essay item:

Compare the composition of the air of a large community and a small farm community, and account for the differences.

In answering this question, the student would have to demonstrate his ability to use information to interpret data.

b. Improve effectiveness of essay items by requiring the student to use knowledge in situations that have not been discussed directly in class. Thus, if students have studied the use of the lever, inclined plane, and wheel, the following instruction might be appropriate:

There is a large stone in the playground which is too heavy to lift and carry away. Explain how you could use simple machines to remove the stone.

In this situation, the student would be using information learned in class to solve a problem that has not been discussed previously.

Another example providing the student with an opportunity to demonstrate his ability to apply principles might result from a study of the properties of metals. In this case, the student could be asked to:

Explain three ways in which you could test the "lead" in a pencil to determine if it is a metal.

Similarly, after a study of experimental procedures, the student could be presented with the following situation:

John heard that weak tea makes plants grow better than tap water. He set up an experiment to find out if this is true. First, he obtained two identical plants. He kept

one plant on the shelf along the wall and the other plant on the window sill. He watered each plant daily. He used tap water on one plant and a weak tea solution on the other plant. He found that the plant which was given the tap water grew better than did the plant that was given a weak tea solution.

The student then could be asked any number of questions relating to this situation, such as:

On the basis of this experiment, should John conclude that tap water is better for plants than weak tea? Why?

or:

How would you perform the experiment to determine if weak tea is better for plants than tap water?

Naturally, the quality of the response would depend upon the grade level of the students, their familiarity with experimental methods, and their ability to make accurate inferences.

c. Frame essay items that measure ability to apply principles, recognize relationships, or make generalizations more effectively by starting with such phrases as "Explain how," "Explain why," "Compare," "Interpret," "Show the relationships," and "Give reasons for." Essay items which start with such words as "what," "who," or "list" generally require that the student merely reproduce certain facts. Essay items that start with such phrases as "What is your opinion of" or "What do you think of" are usually inappropriate for measuring various facets of educational achievement. Frequently, the teacher who uses this type of phrase actually is concerned with the student's ability to analyze a situation or support a particular position and not with the giving of a personal opinion. Therefore, it would be preferable for the teacher to rephrase the question so that the desired response could be elicited.

d. Word essay questions clearly so that the answers which students give will be limited to the specific objectives which are being measured. Too often essay items are so vague and ill-defined that pupils are forced to guess what the teacher wanted. If a student guesses wrong through no fault of his own, or if he interprets a question one way while the teacher wants a different interpretation, the responses become impossible to score, and the advantage of using essay items is lost. Thus, the question *What effect will atomic energy have on the world?* is much too broad and vague. The response could be limited to the destructive properties of atomic energy, or the constructive uses to which it can be set, or both. To be sure that each student will interpret it the same way, the following statement is better:

Plans are now being made for the peacetime use of atomic energy. Give two examples of how atomic energy could be used in agriculture.

In the rephrased statement, there is no uncertainty about what is wanted and about the specific areas to be discussed.

e. Allow sufficient time for students to answer essay questions. Since essay items are used to evaluate the more complex educational goals which require a good deal of thought, the student must have adequate time for analyzing the question, organizing his answer, and then writing it. When students are pressed for time, their responses frequently show **careless thinking and sloppy writing**.

f. Score every objective that is to be measured by the essay question independently. The grading of correct factual information should be judged separately from the grading or organization of material. If grammar, spelling, or writing style are included in the objectives of the unit, these areas should also be scored, but scored separately from the other educational objectives. If only a single score is given for an essay response, the student has no way of knowing how well he has progressed toward each of the objectives established for the particular science unit.

g. Prepare scoring guides in advance. By so doing, judging essay responses can be made more reliable. One of the chief disadvantages of using essay questions has been the inconsistency of the scoring methods. Not only have different teachers reading the same answer come up with divergent scores, but the same teacher reading the same answer has reported different scores on different days. To eliminate such inconsistencies, teachers can prepare a model answer in advance, indicating the factors that should be covered and the credits assigned to each factor. This guide can provide a more uniform basis for evaluating the written responses of each student.

h. Administer several essay tests during the school year to increase the sampling of subject matter. Generally, adequate subject matter sampling can be obtained more satisfactorily through the use of other measuring devices. However, where the essay test is the best instrument for measuring progress toward a goal, it should be used. In essay tests, adequate sampling of subject matter can only be provided for by increasing the number of essay items used. This is not feasible because of limitations of class time; therefore, several tests are necessary.

2. Objective Tests

The objective test was introduced into the classroom to overcome some of the weaknesses of the essay test. One obvious advantage of the objective test is that it permits extensive sampling of the topics covered, whereas the essay test tends to limit the amount of subject matter that can be sampled. Another advantage of the objective test is that the answers can be scored quickly and objectively. In the essay test, scoring is generally time-consuming and sometimes unreliable. The major complaint made against the use of the objective item is that it tends to measure bits of superficial and random information rather than broad understandings

and more complex abilities. But this limitation, when examined carefully, seems to be more the fault of the person constructing the test items than of the inherent nature of the test itself. Items can be constructed that test not only for knowledge but also for the more complex abilities of understanding and reasoning. However, designing such items for an objective test is far more difficult than preparing similar items for an essay test.

It is no longer a question of which kind of test to use because both essay and objective tests can be used to advantage in the classroom. The most important factor is how well an item is constructed. A poorly constructed test fails to achieve its purpose and actually can interfere with the learning process. Therefore, certain guiding principles are offered here to assist the teacher in constructing objective tests so that greater benefits will be derived from the classroom evaluation program.

A. SUPPLY ITEMS. One major type of objective-test item is the supply item. In a supply-item test, the student is required to provide information, usually in the form of a word or a phrase. Generally speaking, there are two kinds of supply items, the short-answer and the completion item. If the problem is presented in question form, it is a short-answer item. If the problem is presented as an incomplete statement, it is a completion item. The following examples show how the same information can be elicited from both forms:

- | | |
|------------------|---|
| 1. Short Answer: | What is the source of energy in a flashlight? |
| Completion: | The source of energy in a flashlight is the _____. |
| 2. Short Answer: | What is the atmospheric pressure at sea level in pounds per square inch? |
| Completion: | The atmospheric pressure at sea level in pounds per square inch is _____. |
| or: | The atmospheric pressure at sea level is _____ pounds per square inch. |
| 3. Short Answer: | What is the chemical formula for hydrochloric acid? |
| Completion: | The chemical formula for hydrochloric acid is _____. |

Supply items emphasize recall of information and are satisfactory for measuring knowledge of specific facts, names, dates, and simple computations. In addition, supply items allow the teacher to sample a large body of subject matter in a relatively brief period of time. In a supply test, the probability of a student guessing the correct answer is reduced to a minimum. However, these items are not well suited for measuring the more complex abilities of understanding and reasoning.

Suggestions for Constructing Supply Items

1. Design items that avoid misinterpretation and require one correct response. The following shows how a poorly stated item can be improved:

Poor: The two most common gases in the air are _____ and _____.

Although the teacher expects students to respond with "oxygen" and "nitrogen," it would not be surprising to find some pupils responding with "invisible" and "important" or any two other qualities. It would be difficult to score such an answer since it is actually correct even though it is not the answer desired.

Improved: The names of the two most common gases in the air are _____ and _____.

2. Design items that require only one or two completions to be made in a statement. When statements are interrupted by many blanks, the meaning of the item is destroyed, and students are forced to resort to guessing.

Poor: A _____ is an _____ for measuring the _____ of the air.

Improved: A barometer is an instrument for measuring the _____ of the air.

3. Place blanks near or at the end of a statement. When blanks are placed at or near the beginning of statement, the student generally must read the statement twice before being able to supply the answer.

Poor: A(n) _____ measures the speed of the wind.

Improved: The speed of the wind is measured by a(n) _____.

4. Do not provide clues to the correct answer. In the previous example, the article is listed as "a" or "an" so that the student who does not have accurate information cannot guess at the correct response. In addition, the length of the blank should not offer the student a clue to the length of the word omitted. It is a good policy to make all blanks a uniform length, but long enough so that the child has room to write his answer.

5. Specify the units in which a numerical answer is to be given.

Poor: The freezing point of distilled water is _____ degrees.

Improved: The freezing point of distilled water is _____ degrees Fahrenheit.

B. SELECTION ITEMS. Another major group of objective tests is the selection item. In a selection test, the student is required to select a response from among those presented to him. Selection items are also referred to as recognition items and include true-false, multiple choice, and matching items.

1. True-False Items

The true-false test is perhaps the most widely used of all selection tests. It generally consists of a simple declarative statement to be judged true or false, such as:

True. False. It is the oxygen in the air which supports combustion.

A variation of the traditional true-false test is sometimes employed which requires the student to correct the item if it is false. The student must supply the correct answer in the blank provided, for example:

The sun is a planet. True. (False.) Star _____

This modified true-false item helps to reduce guessing, and thus provides the teacher with more valid information about the student's knowledge.

The chief advantage in using true-false tests is that the teacher can sample a large body of subject matter in a short period of time. However, the tests are appropriate only for measuring specific pieces of information, rather than broad understandings. True-false items are also very difficult to construct because they have to be limited to statements that are either completely true or absolutely false. As a result, many of the items that are seen on true-false tests are ambiguous and pose difficult problems, especially for the bright student. Another weakness of true-false tests is that they encourage guessing.

Suggestions for Constructing True-False Items

(a) Use statements that are completely true or absolutely false. One of the glaring weaknesses of true-false items is that the capable student generally can think of certain exceptions, and thus finds them difficult to answer, as in this example:

Poor: T. F. The boiling point of water is 212° Fahrenheit.

Improved: T. F. The boiling point of distilled water at sea level is 212° Fahrenheit.

In the first example, certain information related to atmospheric pressure

and kind of water is omitted, which might pose a real problem for these students who see the need for additional qualifications before answering the statement as true. The second example takes these factors into account.

(b) Avoid using specific determiners that give students clues to the probable answer. Words that tend to identify a statement containing them as true or false are called specific determiners. For example, such words as "always," "never," "none," and "all" are found in statements that are likely to be false. On the other hand, words such as "sometimes," "may," "usually," and "could" are found in statements likely to be true, as for example:

T. F. Evaporation *always* takes place more rapidly in summer than in winter.

T. F. Evaporation *sometimes* takes place more rapidly in summer than in winter.

In the above examples, a student without specific knowledge in the area could probably answer these statements correctly by using the specific determiners "always" and "sometimes" as clues.

(c) Avoid using negative statements. Negatives tend either to confuse students by complicating the meaning of the statement or to cause careless errors when students overlook them, as in the following:

T. F. Mercury is *not* a metal.

(d) Avoid lengthy and involved statements. On the one hand, statements that are lengthy are frequently true. On the other hand, they needlessly prevent the pupil from readily recognizing the important factor in the item, for example:

T. F. When a person moves from New York City to Denver, he finds that the reduced atmospheric pressure at higher altitudes alters the forces exerted on water molecules, and as a result, water changes to steam at a lower temperature than along the seacoast.

(e) Avoid using statements that are partly true and partly false. This again leads to confusion and obscures the real purpose of the test item.

T. F. Oxygen, a gas which supports combustion, was discovered by Newton in 1736.

2. Multiple-Choice Items

A second type of selection item is the multiple-choice test. In a

multiple choice item, the student is given an introductory statement, called the stem, and several alternative answers from which he must select the one that is most appropriate. The introductory statement or stem may be in the form of a question or an incomplete statement as follows:

Question form Which of the following foods is the best source of vitamin C?

- (a) raisins (b) grapefruit (c) pears (d) cherries

Incomplete statement We get the most iron from a normal serving of

- (a) fish (b) veal (c) liver (d) ham

Incomplete statement We get the highest caloric value from one ounce of

- (a) lean beef (b) banana (c) white bread (d) butter

In the above examples, four options are included for each stem. There is no fixed rule regarding the number of options used, but generally four or five possible responses are listed because guessing is then reduced to a minimum. With younger children, however, fewer options can be given without destroying the effectiveness of the item.

The multiple choice item is considered the most valuable and most flexible of all objective items. It can be used to measure the degree to which a student can recall factual knowledge as well as measure the degree to which he can use the more complex abilities of understanding and reasoning. Many content areas can be sampled adequately even though the amount of time needed for answering multiple choice items is greater than for true-false items.

The most serious drawback of multiple choice items is that plausible distractors are difficult to construct. As a result, teachers sometimes use options that are obviously incorrect or resort to such alternatives as "all of these" or "none of these," which are more often wrong answers rather than right answers. It would be preferable for teachers to use fewer options than to weaken the multiple choice item by presenting distractors that do not seem plausible to the student. Another limitation of the multiple choice item is that it cannot measure the ability of pupils to organize and present their ideas.

Suggestions for Constructing Multiple Choice Items

(a) **Word the stem clearly and meaningfully.** The stem should present a single problem adequately. Teachers who have had little experience in constructing multiple-choice items probably will find that it is easier to

center the central problem when the stem is in the form of a question than when it is in the form of an incomplete statement. When an incomplete statement does not present a specific problem, the alternatives merely become a series of independent true-false statements with the student deciding which one is more correct than the others, for example:

Poor: A study of plants tells us that

- 1) green plants store food only in leaves and stems
- 2) some green plants grow from bulbs
- 3) green plants need only air, heat, and water to stay alive
- 4) green plants and animals do not have common needs

It is rather obvious that this item does not present a definite problem. Instead of the student being asked to select the best of four choices concerning a single problem, he actually is involved in deciding which of four somewhat related true-false statements is more true than the others. One suggestion which has been made for determining whether there is a central problem in the stem of a multiple choice item is to cover the distractors and see whether the stem, standing by itself, points to a definite problem. This would not be the case in the stem illustrated above. However, it could be improved as follows:

Improved: A study of the ways in which green plants react to sunlight shows . . .

(b) Include in the stem as much of the item as is possible and especially my words that would otherwise have to be repeated in each alternative. Thus, items are improved because after reading the stem, the student knows exactly what to look for before he examines the alternatives, as in the following:

The temperature of the water for sterilizing baby bottles at home should be 1) 112° F., 2) 212° F., 3) 100° F., 4) 312° F.

(c) Design distractors that are plausible to students. The distractors should appear to be reasonable answers to students who do not have the knowledge required by the item. When some alternatives are obviously incorrect, students with inadequate understanding of the material can arrive at the correct response by the process of elimination, for example:

Poor: The process of nuclear fission normally is started in a nuclear reactor by

- 1) neutrons hitting atomic nuclei
- 2) earthquakes
- 3) releasing electrons
- 4) volcanic explosions

This item can be improved by substituting for the implausible responses 2) and 4) new responses that are more closely related to the others, such as:

- Improved: The process of nuclear fission normally is started in a nuclear reactor by
- 1) neutrons hitting atomic nuclei
 - 2) uniting atomic nuclei
 - 3) releasing electrons
 - 4) neutralizing protons

(d) State the problem in positive form. The use of negatives tends to confuse the student and causes careless errors.

- Poor: Which of the following is not an element?
- 1) mercury
 - 2) oxygen
 - 3) salt
 - 4) hydrogen

- Improved: Which one of the following is an element?
- 1) mercury
 - 2) peroxide
 - 3) salt
 - 4) hydrocarbon

(e) Construct responses that are grammatically consistent with the stem. A correct sentence should be formed when each alternative is attached to the incomplete statement. Cues resulting from grammatical inconsistencies should be avoided.

- Poor: The voltage in an alternating current circuit can be stepped down by a
- 1) transformer
 - 2) induction coil
 - 3) oscillator
 - 4) alternator

- Improved: The voltage in an alternating current circuit can be stepped down by a
- 1) transformer
 - 2) rectifier
 - 3) magneto
 - 4) condensor

The grammatical inconsistency in the first example could also be remedied by removing the article "a" from the stem and using the appropriate article with each option.

(f) Use situations that the student has not previously encountered in class when designing items to measure such abilities as reasoning, problem solving, or any of the other higher mental processes. If students are presented with items that have already been used in the text or discussed

in the classroom, the teacher may be measuring only rote memory rather than thinking ability.

3. Matching Items

A third type of selection test is the matching-item test. Typically, such a test consists of two columns of items which are to be associated on some directed basis. The first column is called a list of premises and the second column a list of responses. In the simplest form, the two columns have the same number of items, but the matching test can be made more complex by increasing the number of responses or requiring the use of more than one response item for some items in the list of premises. For most elementary school programs, however, the simpler test is more appropriate:

Directions: In the space next to each item in Column I, place the letter of the phrase in Column II which defines it best.

Column I

- _____ 1. Force
- _____ 2. Energy
- _____ 3. Power
- _____ 4. Speed

Column II

- A. The rate of doing work
- B. A push or pull
- C. Capacity for doing work
- D. Rate of change of position

Matching tests are particularly well-suited for measuring a large body of factual information in a relatively short period of testing time. Matching tests can show whether a student is able to associate events with persons or places, terms with their definitions, principles with examples, and chemical symbols with names of chemicals. Matching items can be scored quickly and objectively, and when the items are well-designed, guessing is reduced to a minimum. The major disadvantage of the matching test is that its use is restricted to a limited number of subject areas. Since the items must bear some relationship to each other, it is often difficult and even impossible to find a sufficient number of related items in all areas of subject content. Another weakness of the matching test is that good items that are not completely obvious are hard to construct.

Suggestions for Constructing Matching Items

(a) The items in the list of premises and the items in the list of responses should be as homogeneous as possible. One method for determining homogeneity is to see whether all of the items in a column can be described accurately by one term. In the following example, this cannot be done:

Poor: *Column I*

- _____ 1. mammal
- _____ 2. insect
- _____ 3. scientist
- _____ 4. gas

Column II

- A. Pasteur
- B. cat
- C. mosquito
- D. hydrogen

It is obvious that the problem presented in this example could be solved by students with the most superficial knowledge merely by the process of elimination. The items are so heterogeneous that no item in Column I could in any way be related to more than a single item in Column II. In the next example, only homogeneous items are used:

Improved: *Column I*

- _____ 1. anemometer
- _____ 2. barometer
- _____ 3. hygrometer
- _____ 4. thermometer

Column II

- A. measures atmospheric pressure
- B. measures temperature
- C. measures wind velocity
- D. measures humidity

(b) The directions should specify clearly the basis for matching the items. The purpose in providing explicit directions is to avoid confusion and clarify for the student the task he is to perform even in situations where the basis for matching seem obvious.

Poor: Match items in Column I with Column II.

Improved: The following problem presents a column listing weather instruments and a column listing what they measure. In the space next to each item in Column I, place the letter of the phrase in Column II which defines it best.

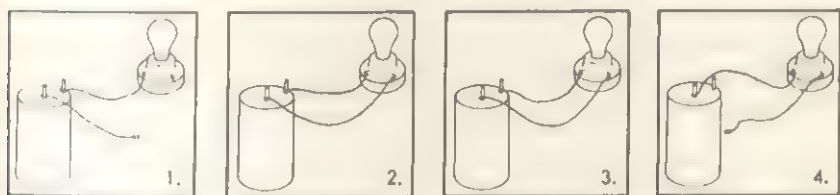
(c) The premises and responses should be arranged in logical order whenever possible. If dates are used, they should be arranged chronologically, and if names are used, they should be arranged alphabetically. This simplifies the task for the student and reduces the amount of time needed for answering these items.

C. OBJECTIVE TESTS USING PICTURES. Objective test items based upon pictorial material can be adapted to measuring a variety of objectives including ability to recall information, interpret data, and apply principles. Furthermore, they are versatile enough to be used in all grades of the elementary school and especially for students with limited reading

comprehension. Since relatively few words are needed for this sort of item to be understood, the teacher can give the instructions orally. Test items based upon pictures can provide the student with clear and unambiguous problems that are interesting, novel, and realistic. It is true that there are certain topics that do not lend themselves to pictorial representation and that some teachers may be poor artists. Nothing can be done about the first problem, but teachers who have little skill in art can find appropriate material in books and magazines which they can either copy or trace. Just using pictures is of little value unless the pictures improve the test item and communicate the problem more effectively than the words they replace.

The following are examples of objective-test items which are based upon pictorial material:

Directions: Mark an X across the picture that shows a complete circuit.

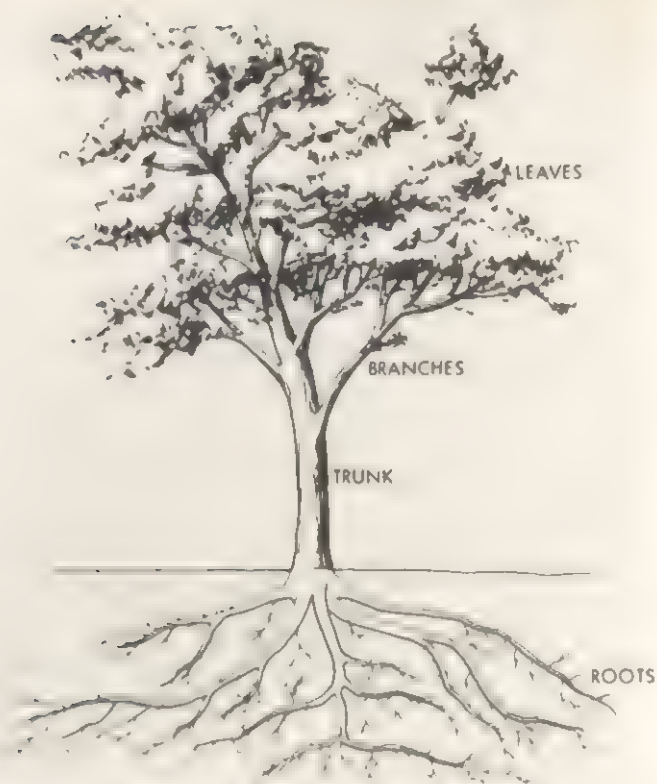


This is an example of a multiple-choice item based on pictorial material. It has been successful in first and second grades with the teacher reading the directions orally.

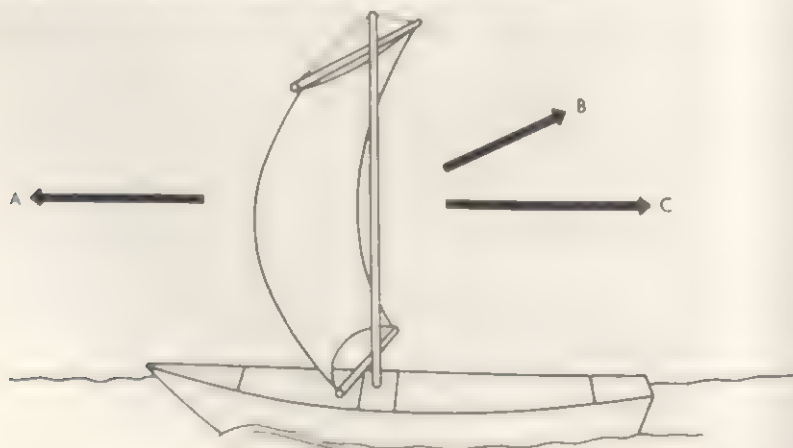
Directions: Here is a picture of a tree with names of some of its parts printed on it. Use these names to complete the statements about the tree.

1. The food for the tree is made in the _____.
2. The tree is held in the ground by the _____.
3. Water is taken into the tree through the _____.
4. The sap is carried to the branches through the _____.
5. The food for the tree is stored in the _____.

This is an example of a completion item using pictorial material. It has been used successfully in second and third grades. Where children have difficulty reading the statements, the teacher reads the statement orally and the children copy the appropriate word from the picture.



Directions Look carefully at this picture of a sailboat being moved by the wind. There are two statements about the boat listed below. Mark an X across the word which makes each statement true.



1. This boat will move because the wind is pushing the
SAIL WATER AIR
2. This boat will move toward _____.
- A. B. C.

This is another example of a multiple-choice item using pictorial material.

Summary Suggestions for All Testing Procedures

4. Check test items against the objectives of the unit to insure that the items relate to the goals and that the test items adequately cover all of the goals. One method of assuring a proper distribution of items is to use a simple coding system. Each objective can be numbered, and as each test item is constructed, it can be related to the objective by assigning it the appropriate number.

b. Check the reading level of each item so that students who are being evaluated in science are not penalized for deficiencies in reading speed or comprehension.

c. Arrange test items in order of difficulty. This provides for more efficient use of the testing time. When difficult items appear first, many students use up most of their time with a few questions and never have time to answer easier questions which may appear later. Furthermore, students who have difficulty at the beginning of a test may soon become **discouraged and give up.**

Group items also according to subject matter and to type of item, and always in order of increasing difficulty. This system has real merit because it reduces confusion and helps the student focus more efficiently on the task to be accomplished.

d Word directions for pupils clearly, specifically, and without ambiguity. The student must know exactly the manner in which he is to select and record his response and also the amount of time allotted for the test.

c. Analyze and classify pupil's responses to tests. They should not just be scored and then forgotten, but can be used by the teacher to gain valuable information regarding student difficulties, teaching techniques, **and the test itself.**

OBSERVATION USED FOR EVALUATION

One of the most useful techniques for evaluating the attainment of many objectives of the science curriculum is teacher observation of student behavior. For example, two objectives of a unit on microbes might be

- 1 To help students learn simple laboratory techniques with which they can grow and prepare micro-organisms for observation and study, and
- 2 To help students learn to use a microscope and a microprojector

Progress toward these objectives can be evaluated best when student behavior is observed in the realistic laboratory situation, but the observation cannot be random or casual. In the first place, the teacher should know exactly what he is looking for. Some indications of a student's ability to use a microscope properly are that he

1. Handles the instrument with great care.
2. Cleans the lenses only with lens tissue or with a soft, clean cloth.
3. Never focuses the microscope downward toward the slides, always moves the objective downward while the eye is away from the eyepiece, and then focuses the microscope upward with the eye looking through the microscope.
4. Arranges the mirror for optimum amount of light.
5. Prepares material for observation, using the techniques most appropriate to whatever is being examined; uses depression slides or bridge arrangements for comparatively large material; uses cover slips to cover smaller items.

1. Checklists and Rating Scales

Having determined the desired behaviors, the teacher can prepare a checklist or a rating scale containing a list of all the actions that relate to student behavior in a particular area. By using a check mark, the teacher can record his observations of a student's performance. The following is an example of such a checklist:

	<u>Always</u>	<u>Sometimes</u>	<u>Never</u>
Is careful in handling microscope			
Cleans lenses properly			
Focuses instrument properly			
Prepares slides correctly			
Arranges mirror for correct amount of light			

The data yield by this checklist can indicate how well students have achieved the objective of using a microscope properly. Such information is usually qualitative and subjective, but when teachers know what they are to observe, the subjective generally can be made more objective.

In the same way, to check whether the children have learned the simple laboratory techniques with which they can grow and prepare micro-organisms, direct observation of the student's behavior in the situation will provide the teacher with more accurate evidence for evaluation than will responses by the children to written questions. Obviously, answers to written questions can give some evidence and should be used too. But what is wanted from the children is not so much the ability to verbalize

about what they should do, as actions which show that they can conduct themselves in the desired manner.

2. Areas Where Observation Is Indicated

An analysis of many areas of the curriculum reveals long-term goals which depend mainly upon observation for their evaluation. For example, there are goals like assuming responsibility, sharing and communicating with others, practicing proper health habits, developing sound attitudes toward learning, or participating in classroom activities. Attaining such long-term goals is an essential part of the science program. Observation is the most effective way by which to determine how well they are being achieved.

To sum up: Observation as an evaluation technique can be effective if the teacher has a clear understanding of the behavior to be assessed. Furthermore, it is incumbent upon the teacher to provide equal opportunities for all the students to respond in the desired manner; every child must have his chance. This requires a conscious effort on the part of the teacher. Finally, a written record of such observations is not only desirable, it is imperative. How these records are made out—whether they be in anecdotal form, in rating scales, or on check sheets—is not too important. Any of these forms can serve the teacher's purposes. What is essential, however, is that the teacher make a written appraisal of what each child actually has shown himself able to perform in certain areas of behavior according to a set of criteria.

APPRAISING CHILDREN'S PROJECTS

Another very significant way of finding out how well children are meeting the objectives of the science program is the teacher's examination of the material which the children produce. After all, what a child does and what he produces can tell much about the way he meets the objectives of the program. For example, we know that third and fourth-graders are collectors. But collections have little worth from a science point of view unless they are organized. One indication of a scientific attitude is the manner in which a person employs a theme for his ideas, and organizes his facts and information in a planned classification. A teacher of the third or fourth grade will want the children to begin to develop the ability to conceive of such themes and such frameworks, and to organize their collections and categorize them accordingly. Thus, the teacher examines a collection of rocks and looks to see how the rocks are grouped. Are they organized according to the place where the rocks are found? Are they grouped as igneous, sedimentary, and metamorphic? Are they exhibited to show certain interesting phenomena such as weathering, water erosion, or ice scratches? Or are they just a hodge-podge of pretty

stones? Neatness, beauty, novelty are all important, but not for science. What is being evaluated as far as science is concerned is the ability to organize and classify materials in a sensible and reasoned way.

Then there are the experiments which children design and the models which they construct to illustrate applications of scientific principles. An analysis of such materials can reveal much more clearly the extent of a student's attainment of the goal of expanded understandings of science than can any paper-and-pencil test. A careful study of such materials is one important way of determining growth toward extended vision and richer insight into the meanings of science and the applications of these meanings to appropriate situations. But such study requires that the teacher be sure about the objectives he is trying to reach. If this evaluation procedure is to have validity, the teacher must appraise a project on the basis of the processes used by the student in reaching his conclusion. Extended vision of one's environment, insight into the scientific concepts derived from facts, and understanding of how such concepts may be applied to specific problems cannot be measured by the quality of the art work involved in lettering the parts of an exhibit. Rather, it is measured by the clarity of thinking that shows in the resultant project. It is measured by the extent to which the exhibit explains a scientific principle through clear and simple examples.

Science reports, too, need this same kind of evaluation. It is not a matter of how many pictures are included in a report. Rather, it is the appropriateness of the pictures as illustrative of the points being made. It is not the length of the report, but the thoughtful organization and clear explanation of the material presented. And, as far as writing goes, a teacher may very well refuse to accept a report from a child because it is not up to the level of neatness or standards of language skill of which he is capable. Misspelled words and poor grammar are not acceptable in science reports any more than they are in English reports. But having to return such a report for rewriting should have no bearing on the science evaluation. In evaluating a science report, the teacher should appraise its worth as science—its accuracy of information, its appropriate explanations, its resultant generalizations, its organization. Science reports must be judged in the light of science objectives.

The teacher must be certain that the objectives upon which the work will be built and upon which it should eventually be appraised are stated in such forms as to indicate the type of resultant behavior desired. If the objective of a weather unit is to have the children understand the water cycle, the exhibit or project which shows, simply and clearly, how water evaporates and then condenses is much more truly an example of sound science thinking than is an elaborate poster of the various kinds of clouds, beautiful as the art work may be. And a simple home-built model of the workings of a gasoline engine—a model made from cardboard, paper fasteners, and crayons—is a much more acceptable project than a plastic

cross-sectional, commercial model of a complex Diesel engine, even though the Diesel engine is put together with great care. What is wanted is a demonstration of how children are thinking, of how well they understand the scientific principles which they are studying. The home-built model shows this; the purchased plastic model does not. Only as the teacher knows clearly the kind of behavior he eventually expects from his students, and as he helps his students carry out projects which lead to this kind of behavior, can he develop an adequate basis for evaluating the work which his students produce.

Bibliography

- Ahmann, J. Stanley and Glock, Marvin. *Evaluating Pupil Growth*. Boston: Allyn and Bacon, Inc., 1958.
- Ahmann, J. Stanley, Glock, Marvin; and Wardeberg, Helen. *Evaluating Elementary School Pupils*. Boston: Allyn and Bacon, Inc., 1960.
- Remmers, H. H., and Gage, N. L. *Educational Measurement and Evaluation*. New York: Harper and Bros., 1955.
- Thomas, R. M. *Judging Student Progress*. New York: Longmans, Green and Co., 1954.
- Thorndike, Robert and Hager, Elizabeth. *Measurement and Evaluation in Psychology and Education*. New York: John Wiley and Sons, Inc., 1961.
- Torgerson, T., and Adams, G. *Measurement and Evaluation*. New York: The Dryden Press, 1954.
- Travers, R. *How to Make Achievement Tests*. New York: The Odyssey Press, 1950.

MATERIALS AND FACILITIES FOR ELEMENTARY SCIENCE

INTRODUCTION

Of all the areas in the elementary school curriculum, science holds a unique position because it offers countless opportunities for the children to do experiments. When children are able to work with a wide variety of materials, their learning experiences become real rather than vicarious. Not only do the children acquire skill in manipulating the same kind of equipment that scientists use, but they also gain greater insight into the key operations, or processes, of science and the scientist.

The strong interest in science education during the past few years has resulted in the development of comprehensive elementary science programs throughout the country. These programs require adequate amounts of supplies and equipment if they are to be effective. Local, state, and federal authorities recognize this need and have shown their willingness to support elementary science financially. Money is now being allocated in school budgets for the purchase of supplies and equipment. Both the National Defense Education Act and the Elementary and Secondary Education Act were created to provide the schools with financial assistance in purchasing laboratory and other special equipment and materials, library resources, textbooks, and other printed and instructional equipment.

It should be kept in mind that the materials should be built around the program, rather than the program built around the materials. The learning activities selected for the program should determine what science materials will be needed. If the science program has a well-developed curriculum guide, then the materials needed will be those necessary to conduct the learning activities described in the guide. This same rationale would apply if the science program were developed around a single or multiple science textbook series.

As a rule, simple supplies and equipment are used in elementary science. This makes it possible to purchase much more materials, and increases the possibility of allowing the children to experiment individually rather than in groups. Also, simple materials can be replaced more easily when they

are damaged or broken. Homemade or improvised equipment can be very useful, if the learnings that result are worthwhile and if an inordinate amount of time and effort do not have to be spent in either finding or making the equipment. However, no science program can be maintained by using only homemade equipment. Many commercial materials must be purchased if the program is to be effective.

Very few elementary schools have adequate classroom facilities for teaching science. Each classroom should have a fixed or movable table for conducting experiments and demonstrations. Water should be easily accessible, and there should be electrical outlets in each room. The teacher should be provided with suitable sources of heat, such as a portable gas burner, a hot plate, and an alcohol lamp. Facilities should be provided for classroom storage of supplies and equipment. This can be accomplished by using either commercial or homemade storage cabinets. Another possibility would be the use of wall counters, with storage space and shelves below, installed along one wall of the classroom.

There will also be many items that are used only periodically. These include special pieces of equipment and an assortment of chemicals. All of these materials must be stored. Each school should have its own central storeroom for science materials. If this is not possible under existing conditions, perhaps some space can be allocated in another supply room. If necessary, large storage cabinets could be purchased or constructed and placed in a convenient location.

SCIENCE FACILITIES FOR OUR SCHOOLS K-12*

National Science Teachers Association

The teaching of science is concerned with helping students understand the facts, concepts, principles, and generalizations of science. Greater emphasis is now given to helping students think critically, be creative in their approach to problem-solving, and develop skills and techniques in the use of scientific methods of thinking and acting. To accomplish these goals and accommodate changing procedures, time, space, and adequate facilities must be provided for a wide variety of learning activities and experiences. This excerpt, a portion of a larger article that deals with science facilities for elementary, junior high, and high schools, discusses nine current trends in science education and their concomitant effects on materials and facilities. Twenty principles for planning facilities are set forth. Finally, specific recommendations are made regarding facilities for elementary school science.

CURRENT TRENDS IN SCIENCE EDUCATION

Facilities that meet today's needs and yet look to the future must be related to trends, just as the trends themselves relate to the evolving goals of science.

An emerging pattern of changes in the teaching of science, as seen by identifiable trends, points toward the necessity for continuous evaluation of facilities and evaluation on the basis of sound educational specifications. Those who are planning facilities for science education today need to weigh their plans in relation to trends in science teaching. The resulting facilities should meet present needs and, at the same time, remain flexible for an evolving science program for the future.

Today's trends indicate . . .

1 Greater emphasis on inductive development of concepts and principles through the discovery or problem-solving approach in science teaching.

Less emphasis is placed on the verification "of basic principles through

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demonstrations and laboratory exercises." As often as feasible, teachers permit students to discover principles for themselves through experimentation and problem-solving. Thus, the teacher often acts as a director of research rather than as the ultimate source of information. At other times, information is obtained through reading, discussion, lecture demonstrations, and even verification exercises.

The laboratories, then, must provide space and equipment for a wide variety of experiments performed by the students under the direction of the science teacher, as well as demonstration facilities. Space for reference work will also be needed.

2. A shift away from teacher demonstration as a prime method of teaching and toward pupil experimentation.

At all grade levels, teaching now attempts to involve the student in inquiry and discovery and uses a variety of methods to help the student learn the basic concepts of science. This trend seems to have special importance at the junior high school level since laboratory teaching at this level is thought to result in continued motivation for science study in the senior high school.

All grade levels need instruments, supplies, and equipment that the students can manipulate. Space should be available both inside and outside the building for pupil activity in all areas of science.

3. A movement toward more pupil-teacher planned experiments and away from simple manipulation directed by detailed instructions.

There is a decrease in the lockstep of requiring all pupils to perform the same experiment at the same time. The teacher also introduces students to methods of planning and carrying out activities that will test their own hypotheses.

Arrangement of facilities must be such that the teacher can direct varied activities with a minimum of traffic and confusion and with a maximum of safety and control. The kind and arrangement of furniture, the completeness of mechanical and electric services at work stations, and the adequacy of safety arrangements are important for success with this type of science teaching.

4. A movement toward science for all students and away from science for only the college-bound students.

Science for all students means not only serving more students but also serving many different levels of ability and motivation.

More classrooms and laboratories will be required, and it will be necessary to provide facilities suitable for a wide range of learning activities and abilities.

5. The traditional science sequence of general science, biology, chemistry, and physics giving way to other sequences and patterns.

New units and new courses in the curriculum, as well as renewed emphasis on earth science and the introduction of study about space, all make specific demands for science facilities in the junior and senior high schools.

Facilities will need to be adaptable to the teaching and learning of broad concepts, to the possible merging of certain subjects, and to the new needs of study of earth and space science. Facilities must also be prepared for the introduction of new subjects as well as rearrangement of the old.

6. More homogeneous grouping of students in science classes

Such grouping facilitates flexibility in, and adaptation of, learning experience on various levels of ability and interest. For example, some educators believe that first-hand experiences may be even more important for the slow or average student than for those of greater intellectual ability.

Facilities and equipment should provide for a wide variety of learning experiences and for ways that these experiences can be appropriate to the learning potential and interest of students of all capabilities.

7. Activities such as science fairs, science clubs, and out-of-class science projects on the increase.

Any large-scale program of science project work places a heavy burden on school facilities.

Where participation in outside science activities is important to a school, adequate facilities must be provided if all of the objectives of the science program are to be achieved.

8. Increased use of audio-visual instructional materials by small groups or by individual students.

It is recognized that there are times, lessons, and objectives for which audio-visual materials are the most appropriate teaching tools available. In other instances, these materials may supplement laboratory or textbook. Such materials have an important role in the teaching and learning of science.

Provision should be made for use of audio-visual materials both by the whole class and by individuals or small groups. Educational television, programed instruction, and other teaching devices may also need to be considered.

9. Increasing provision for flexibility in design and construction of science facilities.

This trend reflects the need for changes in room arrangements required by evolving science curricula and the emerging philosophy which places increasing emphasis on learning science through inquiry and discovery. Flexibility also gives the possibility of adapting physical facilities to new methods and procedures and recognizes that there may be several such new methods during the lifetime of the building.

Flexibility in room arrangement will include furniture and major items of equipment, as well as work surfaces, storage space, and teaching materials.

PRINCIPLES FOR PLANNING FACILITIES

The importance of principles to be observed in the design of science

facilities was recognized by the National Science Teachers Association in the report of its first study devoted to this phase of science teaching. The introductory chapter of this publication contained a list of "General Principles Concerning Facilities for Science Instruction." In the study on which this present bulletin is based, respondents to the questionnaire commented on the principles and ranked them in order of importance for those who are planning science facilities today. At least 88 per cent of the participants in the current study considered each principle to be valid today. The following list is arranged in order of importance, as they were judged by the present respondents.

1. School facilities for science should include space for proper storage of all materials related to science.

Adequate storage for the wide variety of materials and equipment needed in science teaching presents an acute problem in many old and new facilities. This is borne out by the number one rank given this principle. Planners must consider the need for generous and proper storage of such essentials as apparatus, equipment, chemicals, consumable materials, models, charts, audio-visual materials, and tools. Laboratory furniture makers have developed excellent cabinets and shelving for many kinds of storage needs. The quality and flexibility of such furniture will pay big dividends over the years in protecting students and teachers and in reducing loss of apparatus caused by improper or unprotected storage.

2. The planning of science facilities should utilize the ideas of many qualified persons.

Architects, administrators, school board members, and also science teachers, supervisors, and laymen in the community should all be a part of the planning team. If plans are to result in the best possible facility, each planner should recognize and respect the areas of competence of the others. Care must be exercised that the whimsy and idiosyncrasy of any of the planning team not create unworkable or inflexible facilities. A wise balance between creativity and experience should be sought.

Administrators and teachers, for example, must agree on class sizes, number of classes that will be assigned to each room during a given day, number of periods per week a teacher will have for planning and preparation, and number of teachers using each classroom and laboratory.

The science teacher will often be the team member most able to contribute to the educational specifications area of planning. Such specifications should include the objectives of the science program; the variety of methods, techniques, and procedures that will be used; special requirements of the various courses and units of study; and the projected use of the facility both at the time of its completion and in the future.

3. The unique needs of science teaching should be anticipated in planning such general features as floors, illumination, heating, ventilation, plumbing, and electrical services.

The science area requires special planning for materials and structural

details required for the science activities. The use of acids, bases, and a variety of solvents should be considered in selecting materials and finishes for floors as well as for laboratory furniture. Laboratory work requires optimum illumination at all work stations. Electric outlets for 110-120 volt alternating current are also essential at most work stations, and other outlets are needed for audio-visual devices and laboratory equipment. Ventilation will often require fume hoods and rapid venting with resultant adjustment in the heating system in cold climates. Plumbing needs include numerous sinks, especially for the biology and general science laboratories.

4. The amount of space in the science rooms should be adequate for a wide range of essential learning activities.

To accommodate the number and variety of learning activities taking place in modern science classes, more space per pupil will be required than for more formal academic courses; rooms should be wide, rather than long and narrow; and arrangement of laboratory furniture should help to cut down on traffic and confusion. The need for individual work stations in the laboratories has increased, and teachers have found that rooms with a width of 30 or more feet best accommodate such arrangements. Participants in the study agreed almost unanimously that from 35 to 45 square feet per student was essential for efficient classroom-laboratories.

The concept of a science suite or science center has prevailed in the design of many schools. In addition to the classroom-laboratories, some of the essential areas of such a suite are preparation and storage rooms, reading areas, project laboratories, shop facilities, darkrooms, plant growing areas, and animal rooms. Of the total space used for science, approximately three-fourths should be used for classroom laboratories and one-fourth for preparation and storage rooms, reading areas, project rooms, shop facilities, or other supplementary areas.

5. Facilities for science instruction should include provisions for students to do individual experimental work.

Recent trends in science curricula and teaching methods have greatly increased the need for individual experimental work stations. The degree of sophistication of experimental work will vary as the interests and abilities of students vary. Stations for experimentation by all students should be provided, but a project room for highly motivated students must also be included if the maximum potential of these students is to be attained.

6. Furniture adaptable to class, small group, and individual work should be provided for science rooms.

This principle is closely associated with the concept of flexibility in science facilities. Recent designs of furniture for science classrooms make possible rapid changes in work areas for a variety of learning activities. The classroom-laboratory in which rapid shifting from class instruction to laboratory work may take place at any appropriate time is an example of such a facility.

Perimeter arrangement of work counters with regularly spaced outlets for utilities allows the use of movable tables and chairs for different arrangement of work spaces. Fixed peninsular work stations also give considerable flexibility for a variety of learning activities.

7. School facilities for science should include provisions for the science teacher to work on plans, records, orders, tests, and the like

Efficient utilization of the science teacher's time and energy should be considered in planning facilities. Effective science teachers must do as much paper work as do teachers in other academic areas. In addition, they must plan and prepare for many kinds of activities in their daily teaching. They must select and set up the materials and apparatus to be used in the classroom for demonstrations and laboratory experiments. They must select and prepare teaching aids and devices and try them out before the class meets.

Most classrooms and laboratories must be used every period during a school day to accommodate the increasing student population. In such cases a convenient and well-equipped preparation room including outlets for utilities should be provided. This room might also serve as an office for the teacher.

8. Rooms used for science should be so planned and equipped that their flexibility will provide for a variety of uses and for changes and adaptations to meet evolving needs.

Individual laboratory work, small-group activities, whole-class discussions, and demonstrations may require rearrangement of tables and chairs. As curriculum experiences and teaching methods evolve, school facilities must accommodate changes in furniture arrangement and space usage. Walls and utility services should be planned so that expansion of the science facilities into adjoining sections of the building is possible at reasonable costs if new needs become apparent. Increasingly, the rooms themselves are being grouped into a science suite or wing.

9. School facilities for science teaching should make provisions for use of an abundance of real materials and forces.

Developing a functional understanding of science concepts, of cause-and-effect relationships, and of the processes and safeguards of scientific thinking make experiences with real materials and forces essential elements in the methods of science teaching. Facilities must provide space for students to have these first-hand experiences and space for the materials and equipment necessary for a wide variety of such activities.

10. Schools should provide facilities for using audio-visual and other sensory aids in science teaching.

Certain kinds of science learnings may best be accomplished through the use of motion pictures, slides, filmstrips, tape recordings, or television. The need for such supplementary devices and material is important for any quality science program. Thus, the facilities must provide for effective and efficient use of audio-visual devices and materials.

11. Science facilities should permit students and teachers to carry on experimental projects without daily moving or dismantling of equipment.

Rooms for research and experimental projects have become an essential part of science facilities. Teachers must continue to grow in their understanding of science and in their skills in the methods of science. If teachers are to motivate pupils toward continuing in science, they must have an opportunity to demonstrate their own competence in carrying on scientific investigations. The able students may participate in such activities either with their own investigations or as a team working with the teacher on a broader problem.

Space for these activities must be separate from the classroom-laboratory, and at the same time it must be an integral part of the total facility. A well-planned project room with large work stations is needed.

12. School facilities for science should include provisions for students to use published materials in planning their work, interpreting their observations, and studying the activities and findings of scientists.

Students need a place where they can read, think, and plan if they are to experience the processes of the scientific enterprise. Every science classroom, therefore, should contain shelves and files for the wide range of printed materials needed in the science programs—for example, reference books, a variety of texts at different reading levels, pamphlets, research reports, periodicals, and instruction guides for apparatus. These should be readily available in an organized file in the science area, rather than in a library far from the place where they are immediately needed. A reading table and chairs where data can be noted and directions outlined will facilitate use of this resource area of the classroom-laboratory. Some schools are providing carrels, study alcoves, or other arrangements for individual study, either in a classroom or library area.

13. School facilities for science should include provisions for the science teacher to confer with students as individuals or as small groups, and with parents, with the privacy necessary for satisfactory conferences.

The concept of the office-conference room as an integral part of any teaching facility needs no justification in modern schools. Many planners have found that a room which serves both as a preparation room and as a teacher's office is a satisfactory provision for this need. Privacy must be assured, yet easy access to classroom-laboratories and storage areas must be provided. An entrance to the area from the corridor should also be considered to prevent interruption of classes when parents or others come for conferences with the teacher.

14. School facilities for science should reveal that science is a community as well as a school activity.

Many school systems have acquired and developed their own school camps, wooded parks, and nature trails. These areas as well as planetariums installed within the school, become an extension of the science facilities within the community. Learning experiences in earth

science, ecology, and conservation are only a few of the science activities carried on in such areas. Supporting areas within the school building would include reference materials as well as space for display of, or work with, specimens brought back from field trips.

Facilities within the school should also offer opportunity for students to hear guest speakers and to be informed—through bulletin board space, for example—of science-related events and programs in the community.

15. Schools should provide facilities where experiments and projects may be carried on for others to observe.

A wider learning experience for all students is made possible through demonstration and exhibit of other students' individual projects. A demonstration table should be available for such student activities. Other areas for exhibiting the results of individual or group experimentation and projects should be provided within the science area.

16. Rooms used for science should be so designed and decorated that they are pleasant and attractive to the students, teachers, and others who use them.

The atmosphere of science as an active process is an important feature of the science classroom-laboratory. Many participants in the study also expressed the belief that students are attracted to science, in part, by the quality and atmosphere of facilities in the school. Both architects and furniture makers have recognized the importance of this principle. Color and form in room decoration and furniture must continue to be used in planning science facilities.

17. School facilities for science should include provision for constructing and repairing science apparatus and equipment.

Science teachers have found that it is often necessary or desirable to improvise equipment for developing an understanding of certain scientific concepts. Students also find the construction of equipment and apparatus for their own individual experiments to be highly effective in developing their understanding of the problem on which they are working. Therefore, an area within the facilities should provide appropriate work surfaces, materials, and tools for the construction of such equipment. This area may also provide for simple repairs on commercially obtained equipment. Safety considerations are important for this area.

18. School facilities for science should include provisions for students and teachers to use mass media in bringing science to the school and community.

Communication between the school and community is important in our democratic society. Moreover, adequate support for the science program in a school may result from the skillful use of mass media in presenting the activities taking place in the classrooms and laboratories. Facilities should provide opportunities for such activities as science assembly programs, science fairs, store window displays, programs for service clubs, television and radio programs, and news-type photographs of science activities in the school.

19. The selection of the site for a new building should be made, in part, with regard for the potential contributions of the site and its surroundings to the teaching of science.

In some instances, farsighted school boards have been able to acquire undeveloped land for school sites and to select and preserve the natural resources of the area for use in the school's science program. "School grounds are becoming increasingly valuable and recognized as important outdoor laboratories for school programs of study in science, agriculture, mathematics and other subjects." Ecology and conservation are receiving increasing emphasis in the new biological curricula. Therefore, it seems essential that the potential of school surroundings be explored and developed for maximum use in learning experiences. With the cooperation of the community, such areas as school gardens, wildflower and rock gardens, arboretums, school forests, wildlife sanctuaries, bog gardens, fish ponds, nature trails, weather stations, and outdoor classrooms should be developed.

20. School facilities for science should include provisions for displaying both improvised and manufactured products and devices.

Much learning will occur from observing well-planned displays, and students will often be motivated to further learning in science as a result of such vicarious experiences. Nor should the learning that takes place when students themselves plan and make good displays be overlooked. This activity may be a worthwhile learning experience for some students and may lead to further motivation in classroom activities. Therefore, modern science facilities should include display cases and tackboards, with some of these being placed in corridors as well as in the science rooms. Living things and their habitats are well displayed in the open courts of modern school buildings.

FACILITIES FOR ELEMENTARY SCHOOL SCIENCE

In its earlier years, science in the elementary school was chiefly nature study. Natural objects were collected, identified, displayed, observed, and talked about. Incidental and accidental happenings made up a large part of the learning experiences in science. Little or no curricular design prevailed, and in many schools no science could be found.

Educators are now increasingly recognizing the importance of a K-12 program in science. They are also recognizing that such programs don't just happen—they must be carefully planned, constantly evaluated and strengthened, and energetically supported. Facilities, of course, play a large part in the program, but first must come understanding of what makes a good program, time planned for the program, and teachers competent to carry it out. Since not all elementary school teachers will be competent in science, administrators must provide inservice training programs, an atmosphere in which teachers are not afraid to try new methods of teaching, and continuing leadership for the program.

Objectives of Science Programs in the Elementary School

Programs of learning in science at the elementary school level should:

1. Provide experiences through which boys and girls can arrive at some of the concepts of science through observation, inquiry, problem-solving, and study of cause-and-effect relationships.
2. Provide science experiences planned around activities of significance to boys and girls.
3. Organize the learnings in science so that they will result in certain desirable outcomes by the time the child completes the elementary grades—for example, beginnings of habits of systematic observation, of quantitative thinking and representation; some acquaintance with modes of scientific thought; beginnings of a scientific vocabulary; and a desire for scientific explanation.
4. Help the child, wherever possible, to apply the methods of science to arithmetic, language arts, and other studies.

Space should be arranged and facilities and equipment chosen to support these objectives—not just to demonstrate or to be the center of attention in themselves.

Further guidance in planning for science in the elementary school can be gained from familiarity with apparent trends and recognition of relationship between school organization and facilities for science.

Trends in Elementary School Science

Analysis of replies from persons queried in this study indicate trends in elementary school science toward:

1. *Planning of experience in science.* Such planning includes both scope and sequence of science experiences. The content of the program has been broadened with much more emphasis being given to concepts in the physical and earth sciences.
2. *More adequate instructional materials in science.* This is especially true of printed material. Space is needed for housing and using these materials.
3. *Problem-solving activities in science.* The problem-solving approach, using both materials and equipment from the pupils' own environment and commercial scientific equipment is increasingly central to the elementary science program. No longer is the cluttered table in the science corner adequate for elementary school science teaching.
4. *More effective teachers and better programs for preparing teachers for elementary school science.* A deeper understanding of science for children also requires a greater competence in the use of science facilities.

5. *Increased specialized personnel with competence in science.* Resource teachers and supervisors for elementary science are increasingly being used, often as team teachers with the classroom teachers. The effective use of such resource persons depends, in part, upon the quality and arrangement of the facilities within the elementary school.

Science Facilities in the Self-contained Classroom

The organization of a school has a direct relationship to the kinds of facilities needed. Where the self-contained classroom is in the pattern of kindergarten through grade six, at least two alternatives are possible. In one arrangement, work surfaces, storage space, and electric outlets are provided in each classroom. Flexibility within the room is an essential feature, not only for science activities but for learning activities in all areas of the elementary school curriculum. Chalkboards, tackboard, display areas, provisions for projection, workbenches, movable tables, and storage cabinets are necessary for good elementary teaching whether it be in language arts, social studies, mathematics, art, or science. A reading area with a place for a wide range of printed materials should be available with science materials taking their rightful place among these resources.

A dynamic science program creates special needs to be met within the self-contained classroom. The following provisions are essential:

- A work counter with one or more sinks provided with hot and cold water.

- A convenient electric outlet (110-120 volt AC) for a hotplate at the work counter.

- Safe sources of heat for experiments, such as the small liquid petroleum burners.

- Dry cells or a low-voltage direct and alternating current power pack for electrical experiments. (These electric substations may either be portable or permanently installed in the work counter; for safety, they should be installed beyond reaching distance of the sink and its hardware.)

Space for work and for storage should be planned together. Beneath the window ledge, counter tops of sufficient depth provide for some important science activities. They provide space for such things as terrariums and growing plants. Space for an aquarium may be provided but not in a position where it will get long hours of sunlight. When heating units allow, space below work counters can be used for excellent storage spaces for a variety of things for science. Adjustable shelves are essential for efficient use of all cabinet spaces.

Furniture within the room should be movable. Flat-top desks may be placed together for larger work areas, or the furniture can be moved to

clear the center of the room for certain essential science activities. At least one suitable table in the elementary classroom is a great aid in carrying on science experiments and projects. The table, and other tables used for experiments, should have an acid- and water-resistant surface. The workbench with its tools for construction of simple apparatus is likewise an essential part of the facilities.

Many small and rather inexpensive items of equipment, such as glassware, magnets, dry cells, thermometers, pans, and plastic containers should be a permanent part of the equipment for each room. Adequate storage space must be provided, although the storage of science materials should not crowd out the materials needed for other areas of the elementary school program.

The Elementary School Science Center

A science center for the elementary school is an excellent provision for the science program and is an alternative to having all facilities in the classroom itself. The center may function both as a place for storing materials and equipment and as a place for preparing these materials for use in the classroom. At times the teacher may send a student or a small group of students to this area to prepare materials for a science project. A room smaller than a classroom but larger than a storage closet will serve for the center.

The science center needs large amounts of storage space in both closed cabinets and open shelves, a work counter with a sink with hot and cold running water, and electric outlets. A workbench or worktable greatly increases the center's value. Wood, hammer, nails, wire, cloth, metal, string, and many other kinds of construction materials should also be available in the science center.

Larger and more expensive pieces of equipment which should be shared by several classes may well be kept in the closed cabinets in this room. A rollable table may be provided to transport equipment and materials to and from the classrooms and as a table for class experimentation. Careful cataloging of equipment and supplies with storage space for each item increases effective use of the science center.

Elementary Science Laboratories

Another arrangement of facilities for elementary science teaching may be associated with a departmentalized organization of the school, at least in grades four, five, and six. Parenthetically, it should be noted here that many educators object seriously to a departmental arrangement. They claim that certain outcomes of the self-contained classroom cannot be achieved by the regimentation of a departmentalized program. However, until all elementary teachers can be brought to a much higher level of competence in science teaching than they now have, some special

arrangements will be required. In schools that do have a departmental organization, a science classroom-laboratory with adjoining preparation and storage area should be provided. Classes participating in such a program would be regularly scheduled for this room.

The special science classroom-laboratory has many fascinating possibilities for the elementary school, if imaginatively furnished and arranged for young children. It need not be, in fact must not be, a miniature replica of a traditional high school science laboratory.

The teacher in charge must be especially prepared and highly competent in the teaching of elementary science.

Flexibility is an essential quality of a room for science. Rearrangement of the room must be possible with a minimum of effort and confusion. Tables and chairs should be movable and should come in several appropriate heights for the variety of students who will use this room. Folding tables may be used so that large areas of the floor can be cleared for various activities. Adjustable chairs may also be provided.

As much counter space as possible should be provided around the perimeter of the room. Several sinks with hot and cold running water should be spaced within the counter top. Storage below the counter should include both drawers and shelves. Electric outlets should be provided at various points in the room. Storage cabinets in various parts of the facility should include appropriate space for models, globes, charts, large and small pieces of apparatus, plastic items and glassware, hand tools, kits, and tote-trays. A variety of materials for construction should be available.

Facilities for elementary school science should also provide for living plants and animals. Many schools have inside courts. With careful planning and work, such areas may become excellent extensions of the science facility. Small ponds for fish and frogs, or a variety of living plants and small animals may be maintained in such an area. Trees, shrubs, and bird feeders will increase the interest and value of the school's surroundings for elementary science. The science room should be placed so that it can have an exit leading directly to the out-of-doors.

PLANNING A SCIENCE FACILITY*

Lawrence J. Heldman

Appropriate facilities are a necessity if an elementary school science curriculum is to be successful. Dr. Heldman lists alternate ways in which an existing school can obtain a full-time science room. He also lists some necessary criteria for the selection of such a room. Structural changes will have to be made in order to provide for adequate water supply, electrical facilities, storage space, and work areas. Finally, a checklist is included for school personnel as they explore, consider, and plan for their own science facility.

The continued emphasis on science as a part of the elementary school curriculum has caused educators to re-examine the need for appropriate facilities to serve their science program.

The development of a school's science facilities can be realized in a variety of ways and from a variety of possibilities. If the school requires a full-time facility capable of handling a regular class then the educators must look for at least a classroom. If, on the other hand, only a part-time facility is needed primarily for storage and perhaps occasionally used by small groups, then a different type of facility must be sought. The purpose of this article is to explore the range of possible solutions and offer some suggestions for consideration.

There are perhaps three ways an existing school can obtain a full-time science room: (1) By incorporating it in the plans for an addition to the building, (2) Through a decrease in enrollment so that an empty classroom is available, or (3) Through some administrative re-organization of the school such as departmentalization or team teaching that would permit the existing rooms to be set up for curriculum areas. In this last case, the arrangements can be so structured that the existing rooms continue to serve the same number of children, but each room is shared by several classes. The Dual Progress Plan is one example of this arrangement while other variations can be found among some of the team-teaching programs.

Shared use of the facility does not necessarily mean an increase in staff. Some school organizations, however, parallel the programs in art, music, and physical education, by hiring specialist teachers in addition to the

* REPRINTED FROM *Science and Children*, Vol. 4, No. 5, February 1967, pp. 17-19. Copyright, 1967, by the National Science Teachers Association, Washington, D.C. Reprinted by permission of the author and the publisher. Dr. Heldman is Associate Professor of Education at the State University College, Oneonta, New York.

regular staff. What is best for your school system and what you can afford is something you will have to explore.

Assuming that there will be a room available in an existing building, here are some items to consider when deciding which room to choose:

The room should be on the first floor.

It should be as large as other classrooms or larger, if possible.

It should have a door leading to the school grounds or be located close to such a door for easy access to the school grounds.

It should have windows with a southern exposure which will provide a maximum amount of natural light for science experiments and demonstrations.

Facilities such as water and electricity must be available and in sufficient supply. Investigate not only the number of electrical outlets but also the service. How much electrical equipment can operate without blowing a fuse? Can an additional sink be added?

Additional items that merit some consideration concern the proximity to the arts and crafts facility if one exists, and the location of the room in relation to the rooms of the youngsters who will use it most. The professional staff responsible for the total educational program will have to weigh all the advantages and disadvantages before coming to a decision. For once the room is selected and certain structural changes are made, it will be difficult to make alterations.

After the room has been selected the next major step is to effect any structural changes that must take place. Utilities must be considered first.

The room should include at least one large sink with hot and cold water and a second sink if the budget will permit. One of the sinks should be large enough to hold a ten gallon aquarium or a small mammal cage for easy cleaning purposes. One suggestion is to design a sink that sits on the floor, similar in nature to the custodial mop sinks or the base of a shower stall. For example, a unit that is 24 X 36 X 8 inches with a six-inch tile lip would be adequate and especially practical for children of all heights. Remember, that in the elementary school, the science room might be used by children who range in age from five to twelve years. If there is some chance that an exterior greenhouse will be attached to the room at some later date, then one of the sinks should be located along this wall or adjacent to it. Water can then be provided for the greenhouse easily.

Providing additional electrical and plumbing facilities is sometimes difficult and almost always expensive. Devices requiring electricity are becoming more and more common in all schools and particularly in their science facilities. Therefore, it is essential that the services be sufficient for today and for future needs. It is suggested that 100 ampere service be supplied to a circuit-breaker equipped panel in the science room. From this panel, appropriate service could be installed in other parts of the

room. This amount of service should provide for all present needs and future expansion. The number of outlets or other surface installations can then be determined by studying the types of equipment in operation at any one time. These will probably range from the more permanently used aquarium devices to occasionally used equipment such as movie and slide projectors.

The next areas of concern should be the storage units and work surfaces. When considering the space to allot for storage, it would be wise to examine the wide range of materials that are found in the science room. For example:

1. Published materials—*textbooks, supplementary books, paperbound or pamphlet materials, charts, maps.*
2. General classroom supplies—*paper, pencils, compasses, protractors, paste.*
3. Free or scavenged materials—*electrical parts, rocks or other collections, commercial samples.*
4. Chemicals—*special requirements for volatile, caustic, or poisonous items.*
5. Demonstration equipment and supplies—*hundreds of items ranging in size, material, and value from a slide cover slip to a 36-inch globe.*
6. Kits—*a variety of sizes, shapes, and frequency of use.*
7. Miscellaneous—*planting mediums, AV equipment, live specimens, materials requiring other than classroom temperature, hand tools.*

Naturally, storage units that provide for this variety of materials must include open shelves for books, cabinets for maps and charts, various size drawers for the smaller materials, and lockable cabinets for chemicals and delicate or expensive equipment. The use of book carts, tip-out bins, and portable storage units might provide some additional flexibility. Every storage unit should have a label-holding device. Built-in units can be floor-mounted and also hung on the wall. Floor units will provide work surfaces. Wall-mounted units should be hung at a convenient height and the space above them used for storage or for the display of student projects. Work surfaces should have a heat and mar resistant finish. Stainless steel, ceramic tile, and a variety of synthetic materials are available to choose from.

Remember, the arrangements and materials suggested here are only guides to needs and not specifications that set a standard for combined storage capacity in an elementary science room. The storage capacity of the room when completely furnished should meet the needs of your program and be flexible enough to meet future needs. Keep in mind the following when planning:

1. What has to be stored?

2. What combination of storage units will the design of the room permit? What will fit?
3. How much is available to spend?
4. Can the room be added to at a later date?

A woodworking bench is very useful in an elementary science room. Such a unit should be equipped with cabinets and/or drawers for the storage of tools and materials. The top should be hardwood and equipped with at least one vise. In addition, the room should also have a demonstration unit from which the teacher can work or prepare materials. Some of these units are portable while others are built-in. The portable unit has the inconvenience of having to run an extension cord for electricity and carting the water to and from it. The built-in unit should have both electricity and water as an integral part.

A darkroom can be provided in one corner of the room by partitioning it off with drapes. The drapes can be mounted on a track in the ceiling so that they will form a quarter circle when drawn closed. If there are windows in this area, they must be draped and the ceiling light should be separately controlled.

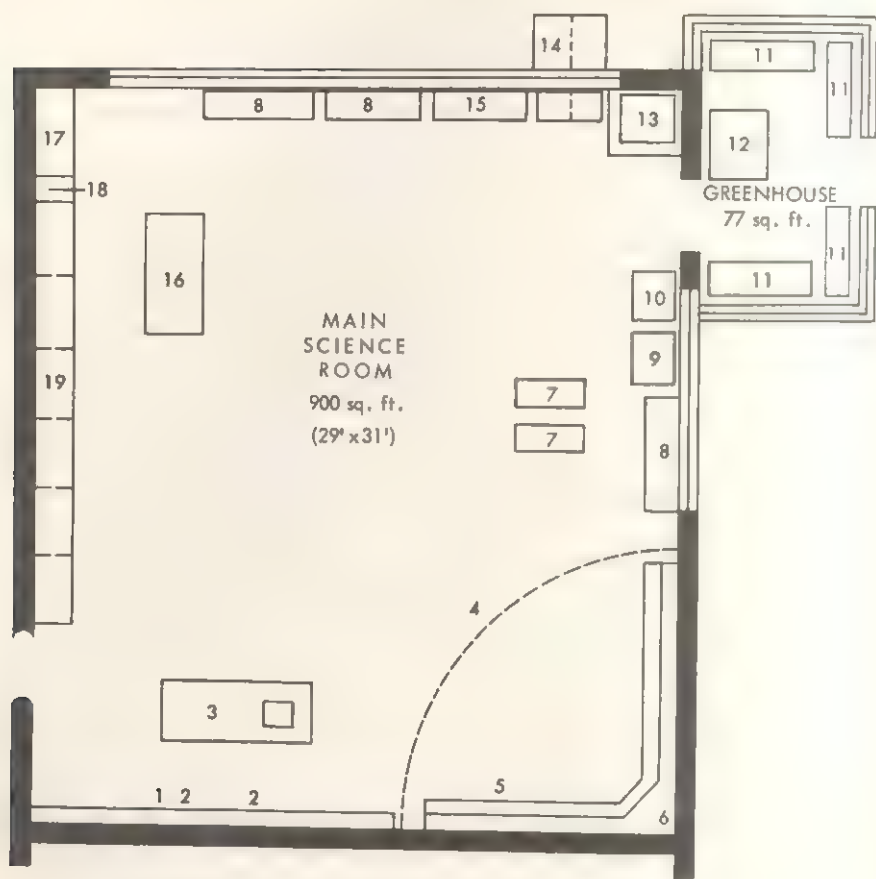
Work areas for the students in addition to the ones provided by storage facilities can include tables or individual desks. Tables are convenient for group work, or the laying out of materials that would extend beyond the top of an individual desk.

The science room, like other classrooms, requires chalkboards and tackboards. Perforated board panels, particularly in the area of the sinks or over the perimeter work surfaces for the display or storage of materials are also useful. In addition, a rod should be hung near the teacher's demonstration area for a fire blanket. Paper-towel dispensers, a first-aid kit, and eye hooks mounted in the ceiling should also be considered. The ceiling hooks should be permanently placed in each corner of the room and in the center and positioned low enough so that wire or string running from one hook to another will not interfere with the lighting fixtures. A larger hook with the ability to hold a block and tackle or other pulley arrangements is an added convenience.

Consideration should also be given to the installation of a refrigerator and stove. These appliances are excellent for special storage, demonstrations, and preparation of materials. A stove has the added feature of being more familiar to teachers and students than open flame heating devices.

If the facility that is available for use must be limited to storage only, more often than not it turns out to be a closet. The location and size of this closet is of prime importance. If it is located within a teaching facility such as a classroom, its use is greatly reduced because all teachers cannot conveniently get to it.

The closet must be located where it can be used anytime during the day without interrupting others. In all probability, the size of the closet



FLOOR PLAN FOR AN ELEMENTARY SCHOOL SCIENCE PROGRAM

LEGEND

- | | |
|--|---|
| 1. Chalkboard | 10. Refrigerator |
| 2. Book shelves above and below chalkboard | 11. Planting tables with storage below |
| 3. Teacher's demonstration area | 12. Preparation table |
| 4. Darkroom curtain | 13. Recessed tub |
| 5. Counter top work area with sink and cabinets below, with tack boards against wall | 14. Indoor-outdoor cages |
| 6. Additional storage above tack board units (above sink) | 15. Storage unit with ceramic tile work surface |
| 7. Portable book carts | 16. Shop table |
| 8. Student work tables (movable) | 17. Double-door storage cabinet with adjustable shelves |
| 9. Oven and range unit | 18. Map and chart storage closet |
| | 19. Student coat storage with tack board on doors |

cannot be altered so the best that can be done with it is to provide adjustable shelves, adequate lighting, and an organization that will make the materials as accessible as possible. Do not overlook the use of corridor shelves, a science cart located in a corridor, or areas under the landings of stairways as possible science storage facilities. But, be sure the use of these areas conforms to fire regulations and building codes before making such arrangements.

A room smaller than a classroom is sometimes available as a science facility. In this case the area can be used for storage and small group instruction. Such areas as offices, conference rooms, unused shower rooms, and certain "basement" areas can be converted into such a facility. A room of this type should include water, good lighting, a work table (a sturdy cart will do), a variety of storage units with adjustable shelves, lockable cabinets, and electrical outlets. Of course, the size of the room will determine the type of activities and the number of pupils that can be served at any one time.

Sometimes a facility the size of a classroom is available if it can be shared among two or more curriculum areas. Such combinations as remedial reading, art, music, and science are practical when the specialists in these areas serve the building on different days of the week. This arrangement necessitates that all facets of the facility, teaching, space, teaching time, tackboards, chalkboards, and storage units are shared.

With any of the "part-time" facilities described (a storage closet, a spare office, or a shared all-purpose room), the major portion of the science program must be taught in the self-contained classroom.

The development of an elementary school science room as an integral part of the total elementary school requires a great deal of planning on the part of the school personnel. As you explore your science facility needs, take these suggestions into consideration and then make plans for your school. Below is a checklist that may be helpful.

CHECKLIST FOR AN ELEMENTARY SCIENCE FACILITY

1. Does the location of the room provide for an easy access to the out-of-doors? ☐
2. Does the location of the room provide for maximum natural light? ☐
3. Is the room located near the arts and crafts facility? ☐
4. Is the room designed in such a way that youngsters will not be hidden from the teacher's view? ☐
5. Has consideration been given to the occasional use of other areas in the building for the science program? ☐
6. Will the room be large enough to accommodate the largest class that is expected to use it? (900 square feet for 25 youngsters) ☐

7. Has sufficient space been allowed for the storage of text and supplementary books? (approximately 50 feet of shelving)
8. Is the storage for maps and charts sufficient and of the proper design? ☐
9. Has a locked storage unit been provided for chemicals? ☐
10. Is there a sufficient number of storage units, including cabinets and drawers in a variety of sizes, to accommodate the equipment and supplies planned? ☐
11. If it becomes necessary to use the science room as a homeroom, have plans been made to accommodate clothing and other pupil articles? ☐
12. Have a refrigerator and stove been included in plans? ☐
13. Will a woodworking bench be included among the furnishings? ☐
14. Has a work area or demonstration unit been provided for the teacher? ☐
15. Have sufficient work areas been provided for student use? (tables and countertops) ☐
16. Are there at least two work areas in the science room with hot and cold water taps and large sinks? ☐
17. Has some consideration been given to the inclusion of a greenhouse, darkroom area, and cages? ☐
18. Have the school grounds been developed so that they can serve the science program as outdoor classroom? ☐
19. Have chalkboards, pegboards, and tackboards been included in sufficient quantity? ☐
20. Will the electrical services provide for today's needs and allow for expansion in the future? ☐
21. Have audiovisual blinds been planned for the room? ☐
22. Have other services such as gas, a television antenna, intercom system, and clocks been given consideration? ☐
23. Has an examination been made of the many miscellaneous suggested items that should be built into the room? ☐
24. Has some list of necessary supplies and equipment been drawn up to serve as a guide for teachers and administrators? ☐
25. Has a plan been devised which will provide annual financing that will allow for the continued growth and development of the elementary science program? ☐

SELECTING EQUIPMENT AND MATERIALS FOR A SCIENCE PROGRAM*

Albert Piltz

Albert Piltz discusses the role of equipment and materials in the elementary science program, and cautions against the use of too complicated materials. The uses of film, filmstrip, opaque, and overhead projectors are presented. Dr. Piltz briefly takes up science kits, and describes the place of both home-made and commercial materials in the science program. The need for adequate storage of equipment is stressed. This article is an excerpt from the U.S. Office of Education bulletin entitled Science Equipment and Materials for Elementary Schools.

In learning science, children plan, discuss, read, report, and listen, but these alone do not add up to effective science teaching. The vital elements are experimentation and demonstration.

EQUIPMENT IN RELATION TO PROGRAM

What is to be taught in a science program and how it is to be taught should determine the equipment and material needs. It would be untenable to purchase a model of a power dam, a science kit, or some object and then build a program around it. If children are to assemble or construct instruments for a weather station, the purpose of the instruction should determine what will be purchased and what will be constructed. For example, a barometer or thermometer may need to be purchased, but a weather vane may be constructed. In each instance the value to the learner should be considered.

Complicated materials and apparatus are usually not suitable for elementary school children, since they may confuse the child and sometimes actually interfere with the principle to be taught. Concepts developed with formal, complex laboratory equipment are often isolated thoughts in the mind of the child. Ideally, most demonstrations or experiments should be such that they can be repeated, varied, or extended at home.

* REPRINTED FROM *Science Equipment and Materials for Elementary Schools*, U.S. Office of Education, Document OE-29029, Bulletin 1961, No. 28, 1963, pp. 20-31. Dr. Piltz is Specialist for Elementary Science at the U.S. Office of Education, San Francisco Regional Office.

The grade level, the geographical location, the textbook or the science guide or manual, availability of utilities in the classroom, and the ingenuity of the teacher are some of the factors which determine the materials and the equipment needs for a given classroom. Also, equipment which might be suitable for individual or small-group experimentation might be too small to be seen easily if used for demonstration purposes. Thus, content and method are factors which bear directly on the needed materials.

Since careful observation is an important aspect of science learning, much valuable experience may be gained by simply viewing the natural environment either in the immediate vicinity of the school or on an extended field trip in which ecological relationships are sought. Often observations which children make of the day and the night sky, of natural habitats of plants and animals, and of land and rock formations require no equipment or materials but result in considerable learning.

The teacher as well as the children can be alert to science materials in the environment. Collections of materials, besides being useful in study, may often lead to careers, hobbies, and leisure-time activities. Children may sometimes be encouraged to bring to school specimens from the out-of-doors or articles from home. It is natural for a youngster to bring a cocoon, a new toy, or a budding twig to school to "show and tell." This becomes a resource for the teacher and a stimulus to learning. A personal contribution helps the child to identify more closely with the project and to develop self-direction and resourcefulness. However, too much dependence by the teacher on the contribution of the children is impractical, since responses are often capricious. The practice of engaging children in participation by having them contribute material or construct apparatus should in no way replace the use of essential equipment and materials provided through the school budget.

PROJECTION EQUIPMENT AND MATERIALS

Motion picture and filmstrip projectors have become almost standard equipment for most elementary schools and, in general, are accessible to teachers. For easy handling, many projectors are mounted on mobile carts which can be moved to the room where they are to be used. Classrooms are either equipped with projection screens and darkening facilities or special rooms are equipped and designated as projection rooms. With the greater availability of motion picture films on elementary school science and with funds for purchase being greatly increased, the use of films is becoming more widespread. The quality of films is constantly improving and they are geared more and more to the instructional program. Science films for elementary school children deal with subject matter that emphasizes, to some degree, the process and the application of scientific principles, as well as the products of science. Films that emphasize the

products of science are oriented to the social studies and center around themes of transportation, communication, and devices which have made life easier in the home.

Filmstrips (or slidefilms) are usually 35mm. in width and often present a sequence of still pictures on a specific area in science. The teacher may use all or a portion of the sequence. Sometimes individual frames from a filmstrip are used for instruction. Synchronized recordings of commentary can be used to create a "sound filmstrip."

There is a great versatility in the use of slides, since the teacher can do his own photography and make or procure a slide for almost any subject. Slides may also be used with sound accompaniment—mainly from record discs or tape recordings. Bird calls and various animal sounds have been effectively used with picture projection. Many teachers make a hobby of taking their own slides in color.

Microscopes have many uses in elementary classrooms. Magnifying a specimen in science often helps the teacher get across an idea which may not be in evidence when the specimen is viewed macroscopically. However, it is important with children not to use so high a power of magnification as to make the part which is enlarged seem totally unrelated to the whole specimen being examined. Even if the teacher helps the pupil properly focus and adjust the microscope for viewing, he is not always certain that he will see what is actually on the slide or even the section of a slide that needs to be observed for study. The problem is even greater with live and moving material. Microprojectors have some advantages in this respect. Although microprojectors are usually limited in magnification compared to some microscopes, the enlargement in projection will generally suffice for most elementary school children. While a microscope can be used by one person at a time, the microprojector projects the object or specimen on the screen so that the entire group can see it. This enables pupils to discuss the material shown on the screen and helps the teacher to clear up certain points for the entire class. In addition, each individual has the same focus on the image at the same time. This may be useful in certain instances.

Since an opaque projector can project on a screen nontransparent pictures, flat specimens, and even shallow containers, its possibilities for elementary science are manifold. Photographic and hand-drawn or hand-written illustrations are commonly used. In addition, botanical and animal specimens of some types can easily be projected. Opaque projectors can be used for children in almost all grades. Some specimens too fragile to be passed around for individual examination can be projected for an entire class. Children also can prepare material for projection.

Overhead transparency projectors have a distinct advantage in elementary science classes because the teacher can face the pupils in front of the class when projecting the material. The teacher can also draw or write on a

plastic sheet in the course of his presentation with an overhead projector. The chalkboard may be comparatively limited in this respect, since a greater number of pupils can readily view an overhead projection with ease. Much of the material used can be prepared by teacher and pupil, using various colored wax pencils for color if desired. With successive layers of transparencies or overlays, various stages in a scientific process may be illustrated or changes which occur in a life science sequence shown dramatically.

As projective techniques and materials are developed further, their place in instruction must be constantly evaluated by both teachers and administrators. It is well to keep in mind that projective techniques are used mainly with groups of children, whereas nonprojective techniques are more for individual use. Both types have their place in a good science program.

KITS, CARTS, AND PACKAGE MATERIALS

Science kits and so-called "packaged science" are of particular concern to program builders because of their popularity and their potential misuse. The busy administrator who lacks the time to select and order separate items from the various catalogues looks upon the kit as a solution to his program and equipment problems. Likewise the teacher who is inexperienced in building a science curriculum welcomes the readymade program. Although the cost of some kits may exceed that of the same items purchased separately, the kits do contain useful materials. Some supervisors of science, however, have emphasized that an overdependence on science kits may have a limiting effect on an instructional program. This equipment, like other types of equipment, can be used effectively or ineffectively. Some persons are concerned with the stereotyped use of equipment, leading to the so-called "cookbook" science. To a large extent the kit may determine the program.

The several commercial kits familiar to most teachers and available in elementary schools have quite a range of price depending on the amount and quality of the contents. They contain a variety of physical science items, such as magnets, spring-balance, thermometer, and magnifier. They are usually marketed in specially built boxes with handles, which makes them convenient to carry.

Some schools or school systems make their own kits; they construct the box and obtain the materials for it from many sources. One type of school-built kit is designed to provide materials for the study of concepts in a specific unit or area in elementary science, such as earth science, the night sky, light, heat, sound, magnets, and weather. In some school systems these kits are called "shoebox kits"; in other places they are called "science-concept boxes."

Some kits emphasize the assembly of a particular kind of equipment, such as a toy motor, telegraph set, question-and-answer boards, or optical system. The skills developed in putting the component parts together would justify the activity, providing the purpose of the activity is clear at the outset.

To relieve the problem of storing and transporting materials and equipment, a cart or mobile arrangement has been made available to teachers in various school systems. Some carts have been constructed in local mill shops; others have been built by school personnel. The cart usually contains basic science materials, both commercial and improvised, arranged in an orderly fashion. Much of the material is contained in boxes or in compartments, according to topics, and is labeled and inventoried. Some mobile units contain a source of water and a source for heat, and can be moved from classroom to classroom.

There are currently available several commercially designed laboratory units for use in elementary schools. Much like the handmade cart, they are more elaborate in construction and are intended to provide the laboratory facilities which many elementary classrooms lack. They come in a wide range of prices, depending on construction, features, and size. In the opinion of many school people these carts have solved, in part, some of the problems of work space, utilities, availability of demonstration equipment when needed, and mobility of use.

THE PLACE OF COMMERCIAL AND IMPROVISED EQUIPMENT

There is clearly a place in the science program for both commercial and improvised equipment. The value of each for its contribution to the educational process must be studied carefully, and the determination to purchase or improvise can then be made in relation to program needs and the purposes to be achieved in the learning activities.

In many areas of science study there are a number of satisfactory ways to demonstrate the same principle. To show the effects of air pressure, for example, the teacher may use either an elaborate vacuum pump or the classical "egg in bottle" demonstration. Each can show the effects of reduced or increased pressure. If resources are plentiful, a variety of experiments may be used. To reinforce learning and stimulate critical thinking, children should be challenged to devise their own methods of illustrating principles and experimenting.

To avoid frustration, all projects for construction should be carefully considered in terms of the children's ability and the availability of tools and materials. Adequate raw materials, tools, and work space are essential. If small-group experimentation is to be encouraged, equipment should be sufficient to allow all children to participate.

In a successful activity in which a model of a solar system was contrived,

children used numerous references for information, many aids, creativity in mounting, and arithmetical concepts in measuring distances and making models to scale. They soon learned the limitations of the models but were stimulated to learn more about the night sky and achieved great appreciation of telescopes and optical equipment. If in construction of equipment a child is helped to better understand a science concept or can better apply a principle of science, then the activity is warranted.

In the past, because science and equipment facilities were often inadequate, teacher education emphasized skills designed to develop resourcefulness in borrowing, salvaging, and improvising materials and equipment to provide low-cost aids for teaching science. As a result, valuable teaching time and effort often were spent in the creation of makeshift facilities. As greater amounts of equipment and materials become available, more instruction can be done with commercial scientific equipment. Elementary school pupils may continue to build thermometers so that they may better understand the principles of temperature and measurement, but they will need precision thermometers for exact readings of temperature. Simple materials from the child's environment can provide rich learning experiences, but dry cells, wire, meters, and other apparatus cannot all be improvised. The child who constructs a telegraph set or miniature motor from metal, wood scraps, wire and nails, learns about materials, electromagnets, and principles of rotation. He also exercises manipulative skill in the activity. The commercial motor, however, gives him opportunity to study construction and, further, to explore the operation that makes motors useful.

ORGANIZATION, STORAGE, AND DISTRIBUTION OF EQUIPMENT

To insure adequate classroom control during periods of class activity, the teacher will need to work out a plan for distributing and collecting materials. Frequently used items should have storage facilities close at hand. When a classroom is being designed to include adequate storage, consideration should be given to the characteristics of each item, such as kind, quantity, size, shape, durability, and frequency of use, and, then, the storage facilities planned accordingly. Storage appropriate for chemicals differs from that necessary for telescopes, microscopes, large charts, or demonstration apparatus. Delicate or expensive equipment which requires special handling, such as galvanometers or microscopes, should be kept under lock and key. Chemicals should also be stored some distance from any equipment that will corrode.

Some costly equipment items which are used infrequently might be stored in a central location either in a school building or central warehouse or in a cooperating children's museum, materials center, curriculum laboratory, or audiovisual center. Much will depend on the facilities available in the school system. If items are distributed to

classrooms from a central supply room in a building, a system of classification, labeling, and inventory will help in locating and distributing them.

Whether equipment is stored in a school building or at an instruction center, it is important that an easy method be devised of making it available to teachers if frequent use of the item is desired. Some provision also should be made for repair and replacement of materials and equipment.

THE FEDERAL PROGRAMS AND THE ELEMENTARY SCIENCE TEACHER*

Albert Piltz

Albert Piltz presents some of the major educational legislation designed to help the teaching of science. Briefly and concisely, Dr. Piltz describes the National Defense Education Act (NDEA), Titles I-IV of the Elementary and Secondary Education Act (ESEA), Title V of the Higher Education Act, the Science Club Act, the training opportunities of the National Science Foundation, the Head Start Child Development Program, and Project Follow Through.

The Federal investment in education—a national enterprise on which the people of our nation now expend \$52.2 billion annually—has taken on a new spurt of growth in the past few years. In fiscal 1964, total Federal funds affecting education—including all Federal agencies such as Department of Defense, National Aeronautics and Space Administration, and the Atomic Energy Commission—came to \$4.5 billion. In fiscal 1965, funds increased to \$6.3 billion, in fiscal 1966, \$8.7 billion, and in 1967, about \$12 billion.

Since 1963, forty-seven pieces of educational legislation have been enacted by Congress. The new laws touch every facet of the teaching-learning process. However, the dramatic educational picture of opportunity and challenge does not mean that spending more dollars will

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necessarily meet the lofty objectives of the recent acts of Congress. It does mean that, however wisely conceived, the new legislative programs could be dissipated in irregular improvements and in haphazard projects and experiments that would have little effect on American education unless the teacher—the vital force in this enterprise—puts forth his strongest effort to meet the challenges of our times.

It would be redundant to elaborate on the significance of science in American education; or to make a case for the science teacher and his vital role of educational leadership. It is incumbent on every teacher to avail himself of the opportunities in science teaching inherent in many of the bills passed by Congress. This article presents a sampling of some major educational legislation in which the science teacher has a stake.

NATIONAL DEFENSE EDUCATION ACT AND AMENDMENTS OF 1964 (PL 88-665)

The National Defense Education Act¹ was signed into law in September 1958, during the period that followed launching of the Soviet Sputnik. The legislation had the immediate aim of augmenting the supply of highly trained manpower in fields relating to security—science, mathematics, and foreign languages.

In succeeding years the Act, administered by the U.S. Office of Education, has had increasing impact on the quality and availability of American education. It has been amended from time to time to extend its coverage to virtually all areas of education. Students from kindergarten through graduate school benefit from its provisions.

Enacted originally for a four-year period, the NDEA was extended in 1963 for two years, and in 1964 for a further three-year extension through June 30, 1968.

The Act is well known for its program of financial assistance to college students. However, assistance also is authorized for programs, under Title III, that buttress the entire educational structure. These include: strengthening instruction in science, mathematics, foreign languages, civics, history, geography, English, economics, industrial arts, and reading; expansion of guidance, counseling, and testing; technical education; improvement of communications media for instructional purposes, teacher-training institutes;² and improvement of educational statistical services.

¹ For additional information on NDEA see "NDEA Purchase Guide" by Leo Schubert and "National Defense Education Act" by Albert Piltz in the April 1965 issue of *Science and Children*.

² The Pennsylvania Science in Action Program is a sample project with combined Federal and state funding under NDEA.

The science teacher benefits directly from the Title III program of NDEA since funds are available for strengthening instruction in science through the acquisition of laboratory and other special equipment and materials suitable for education in science and for minor remodeling, i.e., those alterations of laboratory or other space used for materials or equipment—not building construction.

ELEMENTARY AND SECONDARY EDUCATION ACT OF 1965 (PL 89-10)

TITLE I

Title I offers funds to school districts for special programs designed to meet the needs of educationally deprived children in attendance areas with high concentrations of low-income families.

If science teachers are to participate fully in the effective use of these funds, they must become cognizant of the needs of educationally deprived children and youth and help design programs that would meet the special requirements in science. Some programs for educationally disadvantaged children are suggested in Report No. 143 of the House of Representatives, 89th Congress. These include centers of curriculum materials, mobile learning centers, special audiovisuals, classes for the academically talented, educational summer camps, elementary science laboratories, after school study centers,³ and programed instruction.

Grants may be made to local educational agencies from state allocations for a wide variety of programs, which could include supplementary and remedial instruction, guidance and counseling services, and health and welfare services needed to overcome learning handicaps. Equipment may be acquired and school facilities constructed when necessary to carry out approved programs.

TITLE II

Title II provides funds to states for school library resources, textbooks, and other printed and published instructional materials for the use of children and teachers in all public and private elementary and secondary schools.

The provisions for Title II have direct relevance to science teachers since the program recognizes that teaching and learning today depend upon effective school library materials, high quality, up-to-date textbooks, and a variety of other instructional resources.

³"Science Equipment Library" by Thomas J. Robarge in the February 1967 issue of *Science and Children* describes a program developed in this area.

TITLE III

This program, known as PACE (Projects to Advance Creativity in Education),⁴ helps local school districts relate research to practice through the support of creative supplementary centers and services. School districts are encouraged to take a bold new look at their educational needs and develop programs which illustrate innovative ideas as well as enrich curriculum. It is apparent that this title has special implications for the sciences.

PACE is designed to stimulate and assist local school districts to meet vital needs of education by:

Encouraging flexibility, innovation, and experimentation throughout our educational system;

Providing better services than are now available; and

Supplementing existing educational programs and facilities.

Local public educational agencies or groups of agencies will develop innovative programs based on their own perceptions of need and interest. A program could be as simple as providing an after-school study area or as complex as establishing a model school to serve a group of communities.

Learning laboratories based on new psychological discoveries may be acquired. Instructional materials centers, mobile libraries, mobile science laboratories, home study courses using new techniques of information dissemination, or innovative educational radio and television programing, and special programs in science when schools are not in regular session also may be supported. On a large scale, it would be possible for a community to establish a science research center or museum to provide lectures, demonstrations, and exhibits. Present emphasis is on innovation programs rather than equipment or facilities.

TITLE IV

The individual teacher, a school, a school system, a college, or a university, as well as other public or nonprofit private agencies, institutions, and organizations may apply under Title IV for grants to support educational research. Contracts, but not grants, may be made with profit-making organizations. Questions concerning the wide range of opportunities available under this title should be directed to the Bureau of Research, U.S. Office of Education, Washington, D.C.

⁴ Approximately 200 PACE projects, costing \$16 million, have been funded for work in both elementary and secondary science programs. The Flint Hills Elementary Science Development Program in Kansas and the Oak Ridge, Tennessee Regional Experience Center are two examples.

Title IV also provides funds for constructing and operating the regional centers for research in the field of education. These include Research and Development Centers⁵ and Regional Educational Laboratories.⁶ Educational laboratories differ from R & D centers in their focus, composition, and activities. Although both may work all along the continuum from basic research to dissemination and implementation, centers emphasize research and development while laboratories stress development, dissemination, and implementation.⁷ Science teachers and school personnel should be alert to any such centers established in their area since these centers may offer unusual opportunities for cooperative and supportive efforts in testing and evaluating programs in science education.

Small project research or "mini-grants" are also available under Title IV. To qualify for these grants, a proposal must be \$10,000 or less and completed within an eighteen-month period. To be eligible, an activity must be research or research related, show promise of improving education, have general (not purely local) applicability, and be directed toward communicable results.

HIGHER EDUCATION ACT OF 1965

TITLE V

Title V⁸ is directed toward improving the quality and increasing the number of America's teachers—and at the same time it is directed toward increasing the educational opportunity offered America's elementary and secondary school children. The Title establishes the National Teacher Corps and provides fellowships for graduate study. Members of the Teacher Corps go by invitation to impoverished school districts to supplement the teaching force there. Corpsmen are recruited, selected, and enrolled by the Commissioner of Education. They are either experienced teachers or inexperienced "teacher-interns" who have a bachelor's degree or its equivalent.

Title V also authorizes the Commissioner of Education to award two-year fellowships for graduate study leading to a master's degree or its

⁵ The article, "An Individualized Science Laboratory," by Joseph I. Lipson in the December 1966 issue of *Science and Children*, describes a project affiliated with an R & D Center.

⁶ One of these laboratories is described in an article, "The Appalachia Educational Laboratory," by Carolyn Boiarsky in the April 1967 issue of *Science and Children*.

⁷ *Office of Education, Support for Research and Related Activities*, Publication No. OE-12025. Bureau of Research, U.S. Office of Education, Washington, D.C. p. 4. This publication contains a list of the R & D Centers and a list of the Regional Educational Laboratories.

⁸ This Title may be altered when a bureau is established to administer the Education-Profession Development Act.

equivalent to persons pursuing or intending to pursue an elementary or secondary education career. As many as 4,500 fellowships were awarded in 1966 and 10,000 each in 1967 and 1968. Fellowships are awarded to experienced teachers and to persons who have recently received their bachelor's degrees. Stipends for these recent graduates are in line with similar federally supported programs.

SCIENCE CLUB ACT (PL 85-875)

The purpose of this Act is to strengthen future scientific accomplishment in the nation by assisting in the development of a body of boys and girls with a special interest in science in the secondary schools. Since the appropriation bill governing this Act was not passed, there are presently no funds available for it.

THE NATIONAL SCIENCE FOUNDATION TRAINING OPPORTUNITIES

The National Science Foundation, an independent agency of the Federal Government, is concerned primarily with strengthening basic research and education in the sciences, including mathematics, engineering, and social sciences. Institute and Research Participation Programs are designed to enable teachers to obtain a more complete and up-to-date knowledge of new developments in their particular subject-matter fields. Most of these programs are directed toward secondary school science and mathematics teachers. However, one elementary program of interest to teachers is the Cooperative College-School Science Program, which involves colleges and local school systems in collaborative efforts for local science education improvement. See the article on p. 24.⁹ In the past, NSF has been the basic-funding agency for many of the large national curriculum projects.¹⁰

HEAD START CHILD DEVELOPMENT PROGRAM

The Head Start Program is part of the Economic Opportunities Act (PL 88-452) which provides funds for the establishment and administration of Head Start Child Development Centers. These centers offer education and health, nutritional, and welfare services for pre-school children from

⁹ For additional information on the program see the article, "The Cooperative College-School Science Program," by Howard Hausman, March 1967 issue of *Science and Children*.

¹⁰ All of the national projects in the chart as well as some of their materials have been discussed in *Science and Children* periodically over the past four years. See the biennial indices in May 1965 and May 1967.

economically disadvantaged families.¹¹ Implications for science education are obvious. Detailed information on Head Start can be obtained by writing to your State Technical Assistant's office, Office of Economic Opportunity Program, Office of the Governor, State Capitol Building.

PROJECT FOLLOW THROUGH

Project Follow Through is a joint effort of the Office of Economic Opportunity and the Office of Education. Its purpose is to extend the preschool Head Start program of comprehensive interdisciplinary education into the public schools. Based on the theory that the most appropriate unit for school reform is through the individual elementary school, Project Follow Through is the first federally funded program which provides a vehicle for such reform. This is the first school year of the project's operation in 30 local school districts in 26 states.

¹¹ The program is discussed by Albert Piltz and Minnie Perrin Berson in their article, "Head Start to Discovery," *Science and Children*, December 1965, p. 6.

IMPROVING THE QUALITY OF ELEMENTARY SCIENCE TEACHING

INTRODUCTION

A well structured elementary science program requires the teacher to be cognizant of key concepts from the three broad branches of science: physical, biological, and earth science. This knowledge calls for a more extensive science background than most elementary school teachers now receive in their pre-service training. At the same time, the rapid and continuing increase in knowledge in science makes it difficult for the teacher in the classroom to keep abreast of new developments. It is a well known fact that when teachers have a limited science background, they become extremely reluctant to teach science. Consequently, if the elementary science program is to be effective, consideration must be given to the preparation and professional growth in science of the elementary teacher.

The elementary teacher should be provided with a broad general education which includes preparation in the humanities, the arts, and the sciences. This is necessary because the teacher must teach not only science but also language arts, social studies, and mathematics. Very often the teacher is also responsible for the teaching of music, art, and physical education. A broad education, then, should enable the teacher to coordinate all the learning experiences of the children during the day. Because the teacher is working with children, the education of the teacher should also include an insight into the growth and development, learning, and behavior of the child.

The preparation of the elementary teacher in science should include the learning of as many key concepts in biological, physical, and earth science as time and effort will permit. The teacher should also learn something about the relationship of these branches of science to each other and about the relationship of science to other areas of knowledge. Since teachers tend to teach in the same manner as they have been taught, it is important that the science courses for elementary teachers stress scientific

inquiry and the opportunity to work with the materials of science. Finally, the elementary teacher should be given the opportunity to acquire depth in science, as well as breadth, if the teacher so desires.

In-service education is needed for the elementary teacher to grow professionally and to acquire increased competency in the teaching of science. Typical in-service activities include workshops, seminars, study groups, college courses, and special programs by state and national agencies.

The growth of elementary science and in-service education in science has created a strong need for supervision. Many school systems are now beginning to employ science supervisors. These persons, also called science coordinators or consultants, are experienced and competent teachers who have leadership qualities and a strong science background. Science supervisors can do much to make the science program more effective. They can help teachers by demonstrating special teaching procedures, preparing and distributing instructional materials, and showing how to organize and plan for teaching science. They can help develop in-service programs and, when necessary, conduct the programs. They can inform teachers, administrators, and the public about new developments in science education and research. They can assist in the selection of supplies, equipment, facilities, books, films, and other instructional materials. They can work with elementary, junior high, and high school teachers to develop a continuous K-12 science program for the school system. Finally, they can maintain a liaison with college, university, and state department personnel in science.

The improvement of science education in our elementary schools has become a matter of local, state, and national concern. On the local level the principal and superintendent are beginning to take a leadership role in fostering and instituting curriculum developments and innovations in the teaching of science. State departments of education are strengthening their position and efforts in improving science education in the schools. On the national level the U.S. Office of Education, through its specialists, continues to make excellent contributions to science education. The National Science Foundation, in existence only since 1950, has extended its broad program to include institutes for improving the science teaching of elementary teachers.

GUIDELINES FOR THE SCIENCE AND MATHEMATICS PREPARATION OF ELEMENTARY SCHOOL TEACHERS*

NASDTEC-AAAS

Due to the continuing increase in new knowledge in science, it is necessary to reconsider the preparatory program for elementary teachers. This study is concerned with the nature and quality of programs for the preparation of elementary teachers in the subject areas of science and mathematics. The recommendations suggested here are the results of much intensive and cooperative thinking. The study was sponsored by the National Association of State Directors of Teacher Education and Certification (NASDTEC) in cooperation with the American Association for the Advancement of Science (AAAS) and supported by the Carnegie Corporation of New York.

BASIC ASSUMPTIONS

Guideline 1

The faculty of each institution should design its program for the preparation of the elementary school teacher after careful analysis of the role of (1) the elementary school in American society, (2) the elementary school teacher, and (3) the institutions preparing teachers.

In designing these *Guidelines* to aid college faculties in the preparation of their teacher education programs several assumptions were made. These assumptions should serve as a basis for understanding the recommendations of the NASDTEC-AAAS Studies. They may be taken as a point of departure by faculties in developing their own statements of objectives and in designing appropriate teacher education programs.

THE ROLE OF THE ELEMENTARY SCHOOL IN AMERICAN SOCIETY. The elementary school is responsible for providing educational opportunities for all children. For most children it is the first formal experience with a program devoted to building those general

* REPRINTED FROM *Guidelines for Science and Mathematics in the Preparation Program of Elementary School Teachers*, American Association for the Advancement of Science, Misc. Publ. No. 63-7, 1963, pp. 1-15, by permission of the publisher.

attitudes, understandings and skills needed by every member of society. The program must provide for the continuous mental, emotional, physical and social growth of each child and must recognize that children differ both in potential for growth and in their rate of development. Growth occurs best in an environment that is permeated by the spirit of inquiry, exploration and discovery and one that encourages each child to work toward his maximum self-realization.

THE ROLE OF THE ELEMENTARY SCHOOL TEACHER The elementary school teacher must provide a rich, human and cultural environment in the classroom. He must accept children at their level of development and guide them to further discovery and understanding of their world. He must assist children at their level of development and guide them to further discovery and understanding of their world. He must assist children in using materials and in gaining experiences which develop concepts and stimulate further learning in all the subject areas for which he is responsible. He must relate each new concept to those previously learned in the expansion of the child's knowledge and understanding.

RESPONSIBILITY OF THE TEACHER EDUCATION INSTITUTION. An institution will wish to design a program that will prepare teachers to guide the learning activities of elementary school children. In order to do this, it will select highly qualified candidates, devise ways to study the qualifications and needs of its entrants, the needs and opportunities in its service area schools, and take measures to keep its staff up to date and enthusiastic.

The teacher preparation program will give the student an opportunity to acquire a broad background in liberal arts and sciences, preparation in professional education, and, if he so desires, specialization in a major field of interest.

A teacher education institution that assumes the responsibility for the post-baccalaureate education of elementary school teachers by offering regular graduate study or other types of inservice education will wish to plan its offerings in relation to its four year program and to meet the diverse needs of students.

LIBERAL EDUCATION

Guideline II

The program of preparation for the elementary school teacher should include a broad general education with attention to human growth.

Since children's interests know no boundaries, the preparation of the elementary school teacher must be sufficiently comprehensive to enable

him to encourage and guide these interests into productive channels. In addition, he must be prepared to teach all subject fields offered in the elementary school: language arts, social studies, the sciences, mathematics, health, the fine arts, physical education, and in some cases, a foreign language. To do this well, he must have, beyond subject matter, a working knowledge of human growth, learning, and behavior.

The liberal education of an elementary school teacher should, then, include preparation in the humanities, the sciences, the arts, and human growth, learning, and behavior.

PROCESSES OF SCIENTIFIC INQUIRY

Guideline III

Instruction in science and mathematics should be conducted in ways that will develop in teachers an understanding of and facility in the processes of scientific inquiry and mathematical thinking.

The study of science and mathematics with an emphasis on processes can be a most stimulating experience. When the student has an opportunity to investigate and to discover for himself scientific phenomena and mathematical properties and to formulate principles which he can test, he achieves that sense of accomplishment which should be a product of all scholarly efforts.

In the area of sciences an essential ingredient in the proper education of elementary teachers is the development of skills in scientific inquiry. Such skills include: investigating; observing accurately and reporting concisely results of investigations; formulating and stating questions clearly; designing and executing experiments; conducting field studies; using equipment for counting, measuring and weighing; documenting findings with evidence; classifying materials and ideas; organizing and interpreting data, and, analyzing and critically reviewing scientific literature.

In the area of mathematics, concepts and manipulating skills are both of high importance. Skills without conceptual understanding are relatively sterile as are concepts unaccompanied by skills to give them succinct expression. Mathematics courses should be organized and taught so that there will be continuing emphasis on understanding the deductive nature of mathematics; the importance of mathematical structure in arithmetic, algebra, and geometry and recognition of common ideas that tend to unify these areas; the patterns of logical reasoning; recognition of the role of experience and intuition in mathematical discovery and appreciation of their significance when they appear in the classroom; the importance of the role of precise definitions and the use of mathematical terminology; and, proficiency in manipulating skills.

To accomplish these ends college teachers must look critically at the

instructional procedures in their courses as well as at organization and content. It becomes necessary that college study for prospective elementary school teachers include a wide variety of techniques and materials which lend themselves to the development of these skills. For instance, individual and group laboratory experiences must be provided and should include experimental activities as well as the more traditional exercises involving verification.

An appreciation of the processes of mathematics and sciences can be derived only from an active participation in these disciplines on the part of the student. Prospective teachers must receive preparation that will develop in them the attitudes that they should cultivate in their students.

SUBJECT MATTER IN SCIENCE AND MATHEMATICS

Guideline IV

The program of preparation for the elementary school teacher should include breadth of preparation in the sciences and in mathematics most appropriate as background for the elementary school program, with emphasis on concept development and interdisciplinary treatment

The education of elementary school teachers in the sciences and mathematics should be viewed as a continuous process beginning with the elementary school, including the substantive courses in science and in mathematics in the high school, continuing through the liberal education courses in these fields in college with opportunities for advanced study in the sciences and in mathematics.

In planning a program careful attention should be given to the previous achievement of the prospective elementary school teacher in high school courses. If full recognition is given for the proficiency level already reached by the student, the amount of time required in science and mathematics may not be as great as the following paragraphs appear to suggest. However, for the student who enters college inadequately prepared, more than four years may be necessary to complete an appropriate program.

The preparation needed is in the spirit of the best new liberal education courses. The scope must be very broad with emphasis on the underlying concepts, scientific principles, and the nature of scientific inquiry and mathematical discovery.

Every elementary school teacher should be educated in the fundamental concepts of the biological sciences, physical sciences, earth sciences, and mathematics; in particular those with implications for the education of the elementary school children. Colleges should explore the development of interdisciplinary courses designed to draw upon the subject matter of the various sciences to illustrate these fundamental concepts. The

educational program should be organized so that the appropriate sequences of experiences in the sciences and mathematics are provided. It is essential that scientific inquiry be stressed in all science and mathematics courses designed for prospective elementary school teachers. These elements are to be obtained by providing:

1. Experiences which lead to increased understanding, knowledge and skills in science and mathematics appropriate to the needs and capabilities of children.
2. Experiences which lead to understanding the relationships between branches of science and mathematics and between these areas and other branches of learning.
3. A study of the current and historical developments and philosophies of science and mathematics.
4. Experiences which lead to awareness and appreciation of the continuous expansion of knowledge and the changing emphasis in science and mathematics.
5. Work which will be acceptable as prerequisite for intermediate level undergraduate study in various science fields.
6. Student teaching of many kinds, especially laboratory and field experiences, which illustrate how the methods of science are communicated.
7. Opportunities to increase understanding of problem solving, critical thinking, and methods of inquiry and discovery in science and mathematics.

It is recognized that the skeletal statements of course content which follow are subject to varied interpretations and realizations by institutions. Institutions should expect to devote continuing attention to the ordering and articulation of the separate offerings.

EARTH SCIENCE AND SPACE SCIENCE. Earth science is concerned with the description and interpretation of earth phenomena in all their intermingled, physical, chemical, biological, and mathematical aspects. Its data come largely from field observations, often at widely spread data points, and it is, therefore, concerned with sampling, broad extrapolation of data, and analysis of controlled variables.

Because every child naturally encounters the rocks and the hills, the wind and the rain, and the sun and the stars, earth science serves as a focal point for introduction of other sciences. Furthermore, field examples are available to teachers everywhere that can stimulate creative, disciplined imagination and focus attention on existing phenomena in a search for explanations of our natural world.

The program in earth science for elementary school teachers should consider descriptions and interpretations of features of the earth, the oceans, the atmosphere, and the relation of the earth to the solar system

and the universe. The study of earth science for elementary teachers might contain the following elements: field observations, incorporating elements of sampling, the multiple working hypothesis, methods of making measurements, and the limitations and uncertainties of observations; laboratory measurements including development of experiments, control of variables, and the development of ideas about scale and theory of scale models; display of data, including development and use of maps and cross-sections; and, interpretation and extrapolation of data.

Subject matter should include:

1. Ideas about the origin of the earth in the context of the solar system.
2. The development of an earth model and the methods, sources of data, and uncertainties inherent in the construction of this model.
3. Ideas about the origin and distribution of continents and oceans.
4. Something about geochronology and the history of the earth, including the methods used to determine time relations, such as isotope dating.
5. The distribution and origin of elements, the nature of solids and crystal structure, and derivation of rocks and minerals from silicate and aqueous systems.
6. The sources of the earth's energy and energy changes relating to processes on the surface of the earth.
7. The origin of the earth's atmosphere, climate, and the hydrologic cycle.
8. Evolution of life and the character of the fossil record in extending concepts of evolution backward in geologic time.
9. Something about the economic utilization of earth materials and the relation of earth materials to human affairs.

BIOLOGICAL SCIENCES. For the purposes of instruction, the discipline of biology can be organized in a variety of ways. It is recommended that biology instruction for elementary school teachers present a coherent view of the field of biology and also focus on aspects of the field which are most meaningful and useful for future work and elementary school students. Such foci are:

- A. Kinds of living organism-microbes, plants and animals.
- B. The functioning of organisms, including complementarity of structure and function.
- C. Growth and development of organisms, including genetic continuity.
- D. Interrelations of organisms and environment.

In organizing the foregoing aspects of biology into a coherent view of the field, there are three essential considerations. The first is the reciprocal

relationship between biological inquiry and the development of biological knowledge. To illustrate and develop an understanding of this relationship, college instruction in biology should emphasize: descriptive and experimental aspects of investigation, significant experiences in scientific inquiry (this can be achieved through critical analysis of research reports as well as through laboratory experiences planned to illustrate design of experiments relative to a problem, gathering and interpretation of data, etc.); experience in selection and use of biological literature and, laboratory experience as an integral part of the course. (Living and preserved materials, instrumentation techniques, and field experiences which demonstrate development of biological concepts should be used.)

The second essential consideration in presenting a coherent view of the discipline is to show the interrelationships among the various areas of biology. Broad concepts such as the following can provide a basis for such interrelationships: evolution, diversity of type and unity of pattern; biological roots of behavior; and, community (molecular and cellular as well as ecological). In addition to these concepts, macromolecular biology can be used as a unifying thread.

The third essential consideration is to stress the interrelationships between biology and other disciplines. Some areas in which these are most readily seen are: photosynthesis and respiration; kinematics of enzyme systems; probability and statistics; studies of behavior; ecosystems; biological evolution and culture evolution; and, history of the controversy over spontaneous generation.

To illustrate the foregoing principles to be used in selecting and organizing material from biology for elementary school teachers the following descriptions are provided:

A. *Kinds of living organisms.* Experience in careful observation, description and discrimination with the construction and use of keys for classification often provides experience in the ordering of knowledge. It can provide an understanding of the development of taxonomy as an area of biology by showing the need for frequent review in setting up criteria used in classifying organisms.

B. *The functioning organism.* Consideration should be given to all major kinds of organisms—plants, animals and microbes. Also, life functions should be studied on the level of the behavior of organisms as well as on the molecular-cellular and organ-tissue level. Concepts of significance in studying the functions of organisms are exchange of materials and energy between organism and environment (illustrated by respiration and photosynthesis); regulation and homeostasis; and interaction between environmental stimuli and the organisms. The similarities and differences in these phenomena as they occur in major kinds of organisms—microbes, plants, animals—should be stressed. Differences in

kinds of biological problems and modes of experimentation can be readily brought out by comparing key studies of exchange of materials and energy, homeostasis and regulation, and behavior.

Of course, throughout, the complementarity of structure and function should be emphasized. This would entail careful morphological studies of a variety of organisms. In its broadest sense, morphology explains the gross structural differences between plants and animals; in its narrowest sense, it interprets the molecular organization or the structural unit of living organisms—the cell. By drawing upon the equipment and procedures of conventional microscopy and electron microscopy it can be shown how the biological and physical scientists integrate their efforts, their skills, their investigative approaches and their problem-solving to interpret taxonomy, ecology, embryology, genetics and physiology. However, these outcomes are not likely to be developed if morphology is restricted to preserved materials. Living materials should be used as much as possible. In this way the elementary school teacher can become familiar with opportunities for studying the live materials abundantly on hand in every elementary school environment.

C. Growth and development. The unique contribution which *genetics* can make to the education of elementary teachers is an understanding of how both similarity and variation in successive generations of organisms is possible.

The study of genetics also provides an excellent opportunity for developing an understanding of biological inquiry. Examination of a sequence of key papers in genetics can reveal the development and revision of concepts and the revision of modes of investigation in light of the developing concepts. In addition, the concept of genetic continuity, built up through numerous particular examples of transmission of hereditary characteristics can be used to integrate many areas of study of biological phenomena.

To develop these understandings it is necessary to have first, a precise, disciplined knowledge of the phenomena of mitosis and meiosis; second to understand that there have been different explanations of the mechanisms of these phenomena and why the current explanation is considered most adequate; third, to understand the relationship between the phenomena of mitosis and meiosis and the evidence pertaining to the transmission of hereditary characteristics—i.e., how evidence from cytological, molecular-biochemical and hereditary studies supplement one another; fourth, to see how mathematical concepts have been crucial to the development of the field of genetics; and fifth, to recognize the importance of shifting the unit of study in genetics from individuals to populations.

D. Interrelations between organisms and environment. Modern biology should approach the study of living organisms in relation to their total

environment, both animate and inanimate. Emphasis should be placed on the interactions between an individual organism and into environment as well as on interrelations between populations. Changes in the behavior patterns in response to changes in environmental factors such as radiation, temperature, moisture, mineral elements and associated organisms are subjects for profitable investigation. Any classroom teacher has within his immediate surroundings a ready-made situation for ecological study, without the necessity of costly equipment. Furthermore, ecology provides an excellent means of bringing the earth sciences, physical sciences, social sciences, and biological sciences into a unified whole. Adequate ecological studies lead directly into the areas of health, safety, and conservation of natural resources.

PHYSICAL SCIENCES. The teaching of elements of physics and chemistry in the elementary schools will probably undergo a considerable change during this decade as a result of the work of various study groups. These groups are exploring the questions of concept formation in the sciences, and their findings will have a great effect on ways in which science is presented to children.

It is important that physical science be taught in a way that will emphasize the investigative nature of science. The teaching of physical science should reveal the way in which these disciplines have developed theoretical and abstract concepts. The physical sciences should be appreciated equally for freeing man from the limitations of common sense observation and for providing the technology that has changed man's environment.

In general, emphasis should be placed on depth of treatment, rather than breadth of coverage. Each course should examine at least one specific topic so that the student acquires an understanding of the application of one or more aspects of chemistry and physics in the development of a rigorous and penetrating scientific argument. Guidance for the role of laboratory to accompany these courses may well come from recent course content experimentation in both high school and college. Opportunities must be provided for students to develop their scientific powers through designing and conducting their own laboratory investigations.

An interdisciplinary approach might well be explored by colleges in offering courses that cover the appropriate topics. Emphasis should be put upon the unity of the sciences, however these topics are presented, and every opportunity taken to show interdisciplinary connections. The history and philosophy of physics and chemistry offer many opportunities to relate the physical sciences to studies in the humanities and social sciences, and historical and philosophical topics should be judiciously introduced into the physical science courses.

Studies in the physical science for elementary school teachers should include topics selected from such major areas as:

1. Measurement and experimental errors in chemistry and physics
2. Kinematics in one and two dimensions.
3. Dynamics of a particle—Newton's laws, motion of a projectile, Keplerian orbits.
4. Conservation principles: conservation of mass-energy, momentum and charge.
5. Structure of matter and origins of the atomic theory; kinetic-molecular theory, gas laws, atomic species and the periodic table.
6. Descriptive chemistry of important elements and compounds: formulas and equations.
7. Heat phenomena: temperature, transfer of heat, change of phase.
8. First and second laws of thermodynamics: mechanical equivalent of heat, order and disorder.
9. Waves: waves on strings, acoustic waves.
10. Electric and magnetic fields: electrostatics, electric currents, electromagnetism, electromagnetic induction.
11. Electromagnetic waves: geometrical and physical optics developed for optical waves, but extended to other electromagnetic radiations; the electromagnetic spectrum.
12. The atom-quantum theory of Planck and Einstein, discrete spectra, Rutherford model of the atom, Bohr theory, matter waves and indeterminacy.
13. Chemical bonding: ionic, covalent, metallic.
14. Chemical reactions: rates, equilibrium, energy of reaction. The solid state.
15. The nuclear atom and nuclear energy—radioactivity and isotopes, mass-energy equivalence, fission and fusion, models of the nucleus.

MATHEMATICS. The recommendations of the Committee on Undergraduate Program in Mathematics of the Mathematical Association of America for the preparation in mathematics of prospective elementary teachers are strongly endorsed in principle. The amount of time needed to satisfy the CUPM recommendations is dependent upon the ability and previous preparation of the teacher candidate and will vary from student to student. Programs should be based on at least two years of college preparatory mathematics and more if feasible.

The following are brief descriptions of essential mathematical preparation of the elementary teacher.

A. Algebraic structure of the number system. This is a study of the numbers used in elementary school whole numbers, common fractions, irrational numbers. Emphasis should be on the basic concepts and techniques: properties of addition, multiplication, inverses, systems of numeration, and the number line. The techniques for computation with numbers should be derived from the properties and structure of the

number system, and much attention should be paid to approximation. Some elementary number theory, including prime numbers, properties of even and odd numbers, and some arithmetic with congruences should be included.

B. Algebra. Basic ideas and structure of algebra, including equations, inequalities, positive and negative numbers, absolute value, graphing of truth sets of equations and inequalities, examples of other algebraic systems definitely including finite ones—to emphasize the structure of algebra as well as simple concepts and language of sets.

C. Intuitive foundations of geometry. A study of space, plane, and line as sets of points, considering separation properties and simple closed curves; the triangle, rectangle, circle, sphere, and the other figures in the plane and space considered as sets of points with their properties developed intuitively; the concept of deduction and the beginning of deductive theory based on the properties that have been identified in the intuitive development; concepts of measurement in the plane and space, angle measurement, measurement of the circle, volumes of familiar solids; and, the treatment of coordinate geometry through graphs of simple equations.

These recommendations are minimal. Students who have already covered much of the material recommended by CUPM should be encouraged to extend their studies. A good percentage of the prospective elementary school teachers should enroll in a program comparable to the CUPM recommendations for level II. All students should be prepared to meet changes in content, terminology, and methods in elementary school mathematics with a minimum of inservice assistance. The required flexibility of mind can best be attained by an emphasis on fundamental, widely applicable concepts, such as: set, relation, function, operation, one-to-one correspondence, and isomorphism.

With the inevitable increased future dependence of society on quantitative thinking throughout the many areas served by mathematics it is vital that the teacher bring to the elementary school as much related academic background as possible. For example, elementary notions of probability and statistics may find their way into the secondary and elementary curricula of the future. The applications of these ideas to the physical and social sciences are increasing. Thus, some experience with probability and statistics is desirable. Some knowledge of the significance of the computer and its place in society, as well as some idea of the things that programmers do, would be appropriate.

Elementary school teachers should be thoroughly acquainted with the curricula of the higher grades (junior and senior high school) toward which their pupils are moving. This is in keeping with the more general principle that any teacher should thoroughly understand the subject matter at levels beyond the one that he is teaching.

ELEMENTARY SCIENCE AND MATHEMATICS CURRICULUM
AND METHODS*Guideline V*

The program of preparation for the elementary school teacher should include study of the aims and methods of teaching science and mathematics in the elementary school.

The prospective elementary school teacher should have ample and appropriate opportunity to relate the concepts, information and techniques of college science and mathematics to the educational needs and potentialities of elementary school pupils.

The professional courses should provide both classroom and laboratory experiences specifically designed to develop skill in teaching science and mathematics in the elementary schools. Attention should be given to the identification and development of teaching procedures according to the unique abilities of each prospective teacher.

Professional experiences should include:

1. Systematic consideration of purposes, methods, materials, and evaluation procedures appropriate to the teaching of mathematics and science to children.
2. Study of current trends and research in the teaching of science and mathematics.
3. Laboratory and field opportunities to encourage development of individual initiative in conducting experiments, devising demonstration equipment, developing teacher resources, and planning other types of learning activities.
4. Study of the implications of psychology for the teaching and learning of science and mathematics.
5. Opportunities for prospective teachers to become acquainted with the professional organizations in science and mathematics, their services to teachers, and the importance of active participation in selected organizations including the encouragement they provide for professional growth.

Teachers of methods courses should be well informed about basic mathematical and scientific concepts; the concepts, problems, and literature of mathematics and science education; the nature of the learner; and, the nature of American public schools. They should be excellent teachers who have the confidence of the mathematics, science and education departments.

EXPERIENCES WITH CHILDREN

Guideline VI

Professional laboratory experiences, including observation and student teaching, should provide opportunities for the prospective teacher to work with experienced elementary school teachers who are competent in the subject area, skilled in nurturing the spirit of inquiry, and effective in helping children benefit from the study of science and mathematics.

The institution should have a well-developed program of professional laboratory experiences for future elementary school teachers. With reference to science and mathematics, there should be provision for the effective utilization of personnel appropriately sensitive and competent in science, mathematics and education. This includes the director of laboratory experiences, the immediate supervisor of student teaching experience, the college visitors from the sciences and mathematics departments, and the local cooperating teachers.

The young teacher's confidence in his own ability to teach children science and mathematics in the elementary school is important in initiating and carrying out his own activities. His college experience, including student teaching, should encourage self-confidence. Important in his preparation to teach science and mathematics is contact with teachers who know how to teach science and mathematics to children of differing interests, backgrounds and abilities. Observations and demonstrations should be planned to help prospective teachers relate both content and professional education courses to the interests and maturity levels of children.

The student teaching experience should be under the control of a supervising teacher who has the experience and ability necessary to plan and execute a well-balanced classroom program in which science and mathematics are effectively taught. The cooperating teacher should help the student teacher to develop and utilize teaching plans that integrate effectively science and mathematics in the total elementary school curriculum. He should provide opportunities for student teachers to guide and stimulate children through problematic approaches, and through activities that will result in learning. He should teach student teachers to carry on varied and responsible evaluations with their pupils.

The student teaching supervisory staff should include staff members who have strong backgrounds in science or mathematics education. In addition, these staff members should be well acquainted with the characteristics of children as learners, with the teaching process, should have practical insights into the program of the elementary school, and should make an effort to work with the cooperating teacher.

ADDITIONAL UNDERGRADUATE STUDY

Guideline VII

The program for the preparation of the elementary school teacher should provide opportunities for pursuit of additional undergraduate study in a carefully planned program in science and mathematics.

Prospective teachers should seek depth in a subject matter area, whether it be in the humanities, in the sciences or in the arts. The demands of elementary teacher preparation within a four year college program may restrict specialization to something less than a conventional academic major but there should be opportunities to pursue a subject beyond the introductory level. Additional emphasis on specialized content and instructional techniques in both science and mathematics, for instance, should be available in professional methods courses, in the study of elementary school curriculum and in pre-professional participation and **student teaching**.

In the material suggested below, opportunities for study should go beyond those recommended in the preceding *Guidelines*.

Biological Sciences. For those who seek depth in biological science, additional study of biology should be provided with problem solving laboratory and field experiences deliberately oriented in favor of an investigative approach. Further depth in concepts should be developed in accordance with material listed in *Guideline IV*.

Physical Sciences. For those who seek depth in physical science, additional study in chemistry and physics might be selected from such areas as general chemistry, analytical chemistry, biochemistry, organic chemistry, physical chemistry, introductory classical physics, and **introductory modern physics**.

Earth Sciences. For those who seek depth in the earth sciences, the study selected will depend on the background of the student. Additional study may be done in such areas as astronomy; meteorology and climatology; geology; mineralogy and paleontology, and **oceanography**.

Mathematics. For those who seek depth in mathematics, study should continue into mathematical analysis (including the fundamentals of analytic geometry), abstract algebra, geometry, and probability from a set-theoretic point of view. This program is spelled out very well by the Committee on the Undergraduate Program in Mathematics (CUPM) but currently would probably not be adequately covered by standard programs in mathematics departments over the country.

FIFTH AND SIXTH YEAR PROGRAMS

Guideline VIII

Fifth year and sixth year programs for the elementary school teacher should offer appropriate science courses and mathematics courses which might be applied toward an advanced degree.

Post-baccalaureate opportunities should be available within the institutions or through cooperation with other institutions so that elementary school teachers can extend their competence in the sciences and mathematics with the purpose of becoming better teachers, special teachers, or supervisors. In working out the details of any such program, primary attention must be focused on what would best contribute to increasing the competence and effectiveness of the teacher.

Institutions are encouraged to experiment with new approaches to the development of science and mathematics programs for elementary school teachers at the post-baccalaureate level.

It is recommended that institutions offer graduate level credit for the courses developed. Courses so designed should be considered as adequate to permit further study in regular programs of the departments included **under science and mathematics.**

In the fields of science, these courses will probably differ from those designed for the preparation of professional scientists in the following ways. There will be an emphasis on simple but revealing laboratory experiments, more attention will be paid to an interdisciplinary approach, greater emphasis will be placed on concepts of science relevant to the teaching of science in the elementary school, use will be made of a simple quantitative approach with emphasis on quantitative representation, the historical development of science will be emphasized, and, less emphasis will be placed on the enumeration of scientific facts.

Teachers who engage in fifth and sixth year programs of study should have an opportunity to take additional work in science and mathematics to enable them to teach these subjects more effectively. Teachers who have a special responsibility for science and mathematics in a team teaching plan in their schools will need to strengthen their backgrounds of experience in the study of science and mathematics and to be kept up to date on new developments in scientific research, curriculum, and **teaching methods.**

For fuller realization of a program of science and mathematics in an elementary school, the use of science and mathematics specialists should be considered. Post-baccalaureate programs for the preparation of these specialists should be developed by colleges and universities with qualified staff members who are particularly interested in this endeavor. Such programs should produce specialists who have at least a masters degree which includes substantial work in science and or mathematics.

A specialist may be a consultant, special teacher, resource person, supervisor, or coordinator. The functions of mathematics and science specialists may include: preparing instructional materials and coordinating resources available from the immediate community; assisting in selection of equipment, facilities and instructional materials; developing inservice programs; facilitating articulation of K-12 programs in science and mathematics; providing liaison with college, university and state department personnel in science and mathematics; interpreting new developments in research and teaching to administrators and the public; teaching demonstration lessons; and, providing leadership for evaluation of science and mathematics programs.

INSERVICE EDUCATION

Guideline IX

Inservice education should provide opportunities for the elementary school teacher continuously to improve and extend the competencies required for effective teaching of science and mathematics.

Guidelines I to VIII recommend that elementary teachers have four years of preservice undergraduate education and that they spend a fifth year in rounding out their preparation for elementary teaching and in pursuing advanced work in areas of particular interest. Inservice offerings must take into account the needs of those now teaching whose preservice preparation does not meet *Guideline* standards. Inservice education is interpreted to mean both planned group and planned independent study. Its primary aim is to keep teachers alert to changes in content and method.

The preservice education of teachers should encourage and develop those qualities which enable teachers to supplement inservice course opportunities with a continuing program of independent study. The object should be to develop those habits, ideas, techniques, and powers of judgment and understanding that will not only enable but will also inspire the postgraduate to an active continuation of self-education throughout life. Due to the present explosive rate of growth of knowledge in mathematics and in the sciences, the preservice teacher trainees of today will be required in the future to judge programs and teach materials which they have never studied formally and for which inservice programs will not always be available.

Teacher education institutions, state, and local agencies are urged to provide appropriate inservice programs. School systems are urged in turn to provide time and incentives for teacher participation in these programs. The suggestions made earlier in these *Guidelines* for the preservice

preparation of elementary school teachers should be considered in planning inservice programs for teachers in modern mathematics and science.

These programs should: provide the teacher with analyses of current research pertinent to the teaching of science and mathematics; the study and evaluation of contemporary learning materials for science and mathematics education; and, assist teachers in planning effective applications and in orienting their subject matter to the general or unique needs of their students.

Effective methods of conducting inservice education should be investigated; e.g., programmed instruction, radio, television, correspondence, guides, films, supplementary materials, tapes, and laboratory and field experiences. Mass media coupled with actual personal involvement should be explored.

It is assumed that increasingly young teachers will enter teaching better prepared in science and mathematics. Recurring surveys of inservice education programs will be required to keep up with the changing needs of teachers.

MODEL PROGRAMS FOR THE EDUCATION OF TEACHERS IN SCIENCE*

Stephen S. Winter

This article is a portion of a progress report from the Eastern Section of the Association for the Education of Teachers in Science. Four groups presented recommendations for the preparation of elementary, junior high, and high school teachers in science. The individual reports of the four groups were edited into one comprehensive report by Stephen S. Winter. This portion of the report is concerned only with the professional education (reported by Harold E. Tannenbaum of Hunter College) and with the pre-service science education (reported by Paul S. Hiack of Trenton State College) of elementary teachers.

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I. RECOMMENDATIONS FOR PROFESSIONAL EDUCATION— NON-SCIENCE

Group I considered the desired behavioral characteristics of beginning teachers in the professional, non-science areas. The group generally agreed upon three areas of concern:

- A. Philosophic foundations.
- B. Social foundations.
- C. Psychological foundations.

The major portion of the group's time was spent considering the first two of these areas. It was agreed that the third area should receive further consideration at the next conference of the group.

A summary of the discussion follows:

A. Philosophic Foundations

A prospective teacher of science (K-12) should through his actions, even more than through his oral and written statements, indicate the beginnings of a mature personal and social philosophy consistent with the characteristics of American society. He should demonstrate a consistent value system through the ways he behaves, not only professionally but personally. It was the consensus of the group that one important aspect of the personal behavior of the beginning professional should be determined by his attitudes towards the scientific enterprise of the contemporary world. Included in the desired behavior patterns should be an active understanding of the roles of science in modern society: what science can do *for* us, what science can do *to* us. Furthermore, the beginning teacher should demonstrate his appreciation not only of the rational aspects of science processes but also of the creative and intuitive aspects of these processes.

Finally, the group agreed that an essential behavior of the beginning teacher would be found in his philosophic approach to his teaching assignment. The purposes of education to which he adheres as well as his own views on the role of the teacher in the general framework of the educational enterprise should be clearly evident from his written and oral statements. Even more important, his views and positions on matters of educational philosophy should be evident from his professional behavior.

It seemed to the group that the curricular work related to developing a personal philosophy needed to come early in the pre-service education of the teacher, while those aspects of the curriculum related to the development of a consistent and functional educational philosophy might well come toward the close of the pre-service program, concurrent with or following an internship experience.

B. Social Foundations

The group generally agreed that the social behavior of the young professional would be a very significant indicator of his education. Does the young teacher indicate concern for the social issues of the day both through his own out-of-school activities and through the kinds of activities he fosters and encourages in his classroom? Does the young teacher, through his own behavior, indicate an awareness of the significant contributions of the behavioral sciences to the understanding of contemporary society? Does the young teacher, through professional behavior, indicate a consistency in the philosophy he espouses and the personal and professional activities in which he participates?

The group recognized that social foundations had been included in most curricular designs for at least the past thirty years. It was noted with considerable emphasis, however, that a curriculum was being advocated which included not mere courses in sociology, anthropology, social psychology, and the like, but opportunities for active social participation by students during their pre-service education.

C. Psychological Foundations

As was pointed out earlier, the psychological foundations for teacher preparation did not receive the needed attention from the group. However, the group was in agreement that the young teacher needs to demonstrate his awareness of the characteristics of children and youth of all ages and to be particularly cognizant of the psychological characteristics and needs of the age group with which he is working. A further discussion of this aspect of teacher preparation is contemplated for the next meeting of the group.

D. Other Considerations and Summary

Running through the entire discussion was a constant emphasis on the importance of personal experience in the education of the prospective teacher. We want our pre-service personnel to have experiences in various parts of the nation, to know our cities, our rural areas, our various geographic sectors, our many ethnic groups, and our neighbors, near and far. These should be provided, in so far as possible, through personal activities; where such personal involvement cannot be achieved, the best available vicarious experiences that modern educational media can provide should be substituted. We want our young teachers to have worked with children and youth from many social, economic, and ethnic backgrounds during their pre-service preparation. We are convinced that a well-planned internship, jointly sponsored by the preparing institution and the employing school system, offers great promise (if it is not, indeed, the *sine qua non*) for sound professional preparation. We want our future science

teachers to have personal experiences in the science centers and workshops of the nation, under the supervision of practicing scientists.

In short, we see the education of a future teacher as something much broader and deeper than a mere series of college courses, either in the liberal studies or in professional education. We propose during our further deliberations to turn to a consideration of the kinds of activities we would advocate for the preparation of such teachers.

II. RECOMMENDATIONS FOR PRE-SERVICE EDUCATION OF ELEMENTARY TEACHERS

Group II considered that the science education of the individual teacher will depend in part on the extent of his responsibility for teaching science. Various organizational patterns based on this assumption were discussed. It was recognized that additional research is needed to resolve the question of which pattern will best support the teaching of science in the elementary school. Therefore, at present the general classroom teacher should be trained to assume responsibility for the teaching of science and should have available adequate consultant help in this area. Adequate help in this context was defined as a science consultant for each building and, in addition, a teaching staff of which 20-25 per cent has a science emphasis pre-service preparation. A staff so prepared would seem to offer good flexibility should it become apparent that some other administrative pattern is more desirable.

The group then identified the needs of the personnel in this organization for scientific instruction. The needs of all teachers were identified and recommendations were made for the pre-service education programs of the three types of teachers: the general classroom teacher, the teacher with a pre-service emphasis in science, and the science consultant. However, the group also recognized that additional research is needed in all areas of elementary school science, especially in the area of teacher preparation.

A. General Competencies for Elementary Science

Among the competencies necessary for effective teaching of elementary science which are directly related to pre-service education in science are the following:

1. Awareness of content and structure of science, of the relationship among the branches of science, and the relationship of science to other areas of knowledge.
2. Skill in working with the materials of science.
3. A knowledge of and skill in the use of methods which have been shown to be useful in achieving the objectives of elementary school science.

4. The ability to work with children who have special interest or ability in science and to assist further in the development of that interest and ability.

B. The General Classroom Teacher

This preparation would include training in each of the broad course areas of science, *i.e.*, physical, biological, and space science. Twelve to twenty hours of such science courses should be completed. These are to be courses in which the major ideas of these areas are used as unifying concepts. Laboratory and field work are considered essential. In addition, a methods course specifically directed toward teaching of science in the elementary school must be included.

C. The Teacher with Pre-Service Emphasis in Science

Preparation here includes all the requirements for the general teacher plus additional courses in formal science comprising about one fourth of the total pre-service preparation. Student teaching in science is assumed to be an integral part of the pre-service preparation and is not included in the formal science course preparation.

D. The Science Consultant

This area requires the above preparation plus teaching experience on the elementary level and at least one year of courses on the graduate level.

IN-SERVICE SCIENCE ACTIVITIES FOR THE ELEMENTARY SCHOOL TEACHER*

Marjorie S. Lerner

Marjorie Lerner describes how elementary school teachers can continue their professional growth through varied in-service activities. In-service education in elementary school science can be derived from three basic sources: programs occurring within the local school system, opportunities

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provided by colleges and universities, and activities that can be self-initiated by the teacher. Dr. Lerner also discusses briefly the role of the school administrator in promoting effective in-service education.

The professional growth of the elementary school teacher is a necessity as long as the teacher continues to teach. In order to develop and maintain a high level of competence, the teacher must be provided with continued opportunities for in-service education in all areas of the elementary school curriculum.

Today there is a vital need for in-service education in the area of elementary school science. There are several factors responsible for creating this need. A number of new programs have been developed based on an approach to the teaching of science in the elementary school which stresses the development of the skills or processes of science, and which also aims for the inculcation of scientific attitudes and critical thinking. Programs such as these require elementary school teachers to review and extend further their understanding of the different ways of teaching science.

The recent explosion of science knowledge has produced an impact all the way down to the elementary school, making it imperative for teachers who are already in service to upgrade their science knowledge and background. The National Defense Education Act and also the Elementary and Secondary Education Act have made it possible for the elementary schools to acquire a large quantity and variety of much-needed scientific equipment. As a result, teachers must now become familiar with many different kinds of equipment, learn the purposes for which the equipment can be used, and develop proficiency in manipulating the equipment.

THREE BASIC SOURCES FOR IN-SERVICE EDUCATION

In-service education in science for the elementary school teacher can be derived from three basic sources. First, there are programs that can operate within the local school system. Second, there are opportunities provided by colleges and universities. Third, there are in-service activities that can be initiated and sustained by the teacher alone.

Within the Local System

WORKSHOPS. Science workshops can be helpful to teachers in a number of ways. They can be used to evaluate and revise an existing science program, to organize and develop a new science program with scope and sequence, to coordinate a science program so that it becomes part of an over-all K-12 science program, to construct teaching units, to

investigate and determine ways of obtaining and using materials and equipment, to select textbooks and reference books, to provide the teachers with a series of lecture-demonstrations by science specialists, and to help the teachers become more proficient in methods of teaching science to children.

Science workshops are usually conducted under the leadership of a science supervisor, if the school has one, or by a special committee appointed for that purpose. In some workshops academically and professionally trained persons are asked to serve as consultants and as resource specialists to provide either science information or methodology or both. Some workshops make use of their high school and junior high school science teachers as well.

What characteristics are necessary for a successful workshop? To begin with, workshops cannot be artificial situations with manufactured problems. The problems must be of real concern to the teachers who are participating in the workshop.

In order to ensure that teachers have profitable experiences, workshops should be cooperatively planned with carefully designated objectives. These objectives may be immediate objectives or long-range objectives. For example, a workshop for elementary teachers to acquaint them with the use of several new pieces of equipment has an immediate objective of developing teacher competency in using this new equipment. This new equipment is then scrutinized in perspective with other science equipment, and decisions are made as to where and how this new equipment will best be used. An example of a workshop with long-range objectives would be one where all the science equipment is evaluated, for the purpose of determining specific needs for the future rather than ordering new materials on a "guess" basis.

Some workshops should be specifically designed for the teacher new to the local system. New teachers need orientation to the guiding philosophy in the science program. New teachers also have to see the entire scope and sequence of the science program in order to understand their specific role in the program. Workshops designed to help new teachers learn what resources are available to them and where they may obtain assistance in their science teaching can be of tremendous assistance.

The experienced teacher usually has problems that are different and more sophisticated than those of the new teacher, and therefore needs a workshop with different objectives: How do I apply new approaches to teaching science at my grade level? How do I recognize changed scientific behavior? How do I evaluate my teaching in terms of desired changed behavior? How do I construct valid tests for the objectives set forth in the science program? How do I individualize science instruction? What textbooks are best suited to the program?

COMMITTEE WORK. Teachers can further their professional growth by serving on both small and large committees. Committees provide a wide range of opportunity for in-service education because they permit teachers to engage in many types of activities. Teachers may be encouraged to try out new science programs and report on the progress of such programs. Perhaps the teacher will design new activities to be incorporated into new programs. The teacher can become involved in writing curriculum materials. The study of current research and literature is an important facet of science curriculum development. There are opportunities for the exchange of ideas with other teachers and with various science supervisors and consultants. In evaluating programs and materials, the goals for teaching science in the elementary school become clarified.

THE SCIENCE SUPERVISOR. Quite often elementary teachers fail to realize that their most immediate source for a wide range of in-service activities lies within their grasp by making proper use of their science supervisor. The following is only a partial list of the various ways teachers can obtain help from the science supervisor.

1. Request the observation and evaluation of the teaching-learning situation.
2. Have the science supervisor teach a science session, perhaps one that involves the use of science equipment.
3. Discuss new ideas or approaches to the teaching of science, and request aid in carrying them through.
4. Request assistance in locating needed equipment or in constructing simple equipment.
5. Seek aid in locating or evaluating instructional material.
6. Ask for a specific type of workshop to help solve special problems.
7. Seek advice on local resources.
8. Request aid in planning profitable field trips that will enrich the science program.
9. Ask for help on how to use new equipment or materials.
10. Request the recommendation of certain teachers to be visited and observed for competence in teaching science.
11. Ask for recommendations for professional literature that will assist the teacher in teaching science.
12. Request aid in the construction of tests that will best suit the goals and objectives of the science program.
13. Seek aid in the selection of appropriate films, filmstrips, and other audio-visual materials.
14. Seek advice on summer offerings at local colleges and universities.

Even though this is a partial list of the ways the science supervisor can help the elementary school teacher, it clearly shows how the science supervisor can be a valuable resource person for assisting teachers to continue their professional growth while teaching.

THE ROLE OF TELEVISION. Television possesses tremendous opportunities for use in in-service education of teachers. Television has the advantage of being able to reach large numbers of teachers through a single telecast or series of telecasts. Teachers can learn much by observing a skillful classroom teacher work in her classroom. By using television, this one skillful teacher can be observed by a great many teachers.

The science supervisor often needs to serve large numbers of teachers. His time and efforts can be conserved through the use of television. New advances in science can be brought to the immediate attention of teachers through the use of science consultants. Entire college courses are now being taught on television. Perhaps here is the opportunity for the elementary teacher to obtain needed knowledge and background in physics, chemistry, geology or astronomy. Some instructional courses are presented during the pre-school hours, others during the school day.

Colleges and Universities

An examination of the backgrounds of most new elementary school teachers reveals in most cases a woeful lack of science background. Our colleges and universities often allow the science requirements for graduation to be fulfilled by the election of just one year of a science in an area which the college student chooses. It is, therefore, not uncommon for the elementary school teacher to arrive on the job with a one-year sequence in biology and, perhaps, the professional science methods course. In many instances, it is possible for the new teacher to have had absolutely no laboratory experience in fulfilling the college science requirement. Even the elementary school science methods may be part of a multiple methods course involving other elementary curricular areas such as social studies and/or mathematics. Yet a cursory examination of elementary science textbooks reveals that only about one third of the science content is in the area of the biological sciences. Approximately another third is devoted to the area of physics. The remaining third is concerned with the areas of astronomy, geology, meteorology, and chemistry.

It is quite evident that a four-year college program cannot produce elementary teachers with the proper science background to teach elementary school science effectively. After a year or two of teaching, therefore, elementary teachers should begin to become aware of the gaps in their science background and should begin to fill these needs. Summer study at colleges and universities can fill these gaps.

The teachers must be careful, however, to select courses that truly fill their needs. An introductory course in geology can be more immediately fruitful to the elementary school teacher than an advanced course in educational psychology. The teacher should select science courses that will provide laboratory experience. Teachers without such experiences are generally fearful of science equipment. As a result, experiments and/or demonstrations will rarely occur when such teachers are teaching science.

Many school systems base salary increments only upon graduate study and additional degrees. As a result, teachers cannot gain recognition or credit by taking the introductory course, even though such a course meets a definite need for the professional growth of the teacher. Consequently, teachers are discouraged from taking beginning courses in a science area. There is a great need for school systems to re-evaluate their attitudes toward such introductory courses. In the long run, it is the child in the classroom who benefits by the teacher who seeks and attains competence in subject matter. This, then, should be the criterion used by school systems rather than the level of the college course taken by the teacher.

National Science Foundation

The Cooperative College-School Science Program (CCSS) of the National Science Foundation provides opportunities for colleges and universities to work with schools and school systems in improving elementary and secondary school science and mathematics programs. Many of the projects in CCSS have as their purpose the introduction into the classroom of one of the new science or mathematics curriculum programs which have been developed. These projects are scheduled during the summer or the academic year or both. Projects which include intensive summer work on the campus of the sponsoring college or university usually have a coordinated academic year phase as well. The academic year phase frequently involves study and laboratory investigations or demonstrations in the participants' own schools, or Saturday or weekday meetings on the college campus, or both.

Self-Initiating Activities

Elementary teachers can and should afford themselves the opportunity for professional growth through reading current professional literature. *Science and Children* is an excellent publication of the National Science Teachers Association, devoted exclusively to science for grades K-6. Frequently, this publication presents outstanding talks from the association's annual convention or from regional conferences. *The Grade Teacher* and *The Instructor* have devoted entire issues to science for the elementary grades. *School Science and Mathematics* (the publication of the Central Association of Science and Mathematics Teachers) and *The Science Teacher* (another publication of the National Science Teachers

Association) occasionally feature articles pertinent to elementary school science. The same holds true for the *National Education Association Journal*. If these publications do not appear in your professional school library, consult your school librarian. She is usually eager to obtain subscriptions to those professional publications that will be helpful to the teacher.

Membership in a professional science education organization on a local, state, or national level will afford many opportunities for professional growth through bulletins, newsletters, publication announcements, or attendance at meetings, regional conferences, and conventions. Many publishers of elementary science textbooks issue curricular bulletins and charts, and are always interested in communicating with teachers. In school systems where in-service education is entirely an individual matter, self-initiating activities make it possible for elementary teachers to continue their professional growth.

THE ROLE OF THE SCHOOL ADMINISTRATOR

The school administrator plays a crucial role in the effectiveness of any in-service education program. He must be aware of the strengths and weaknesses of his teachers, be able to identify their widely divergent problems and needs, and provide a variety of opportunities to help the teachers according to their specific needs.

He should encourage teachers to seek new approaches to the teaching of science. Provisions must be made for teachers to observe good teaching practices and to attend workshops, conferences, and conventions. He must provide necessary materials, establish effective schedules, and coordinate the activities of teachers, supervisors, and consultants. Unless the administrator plans for school in-service activities, they will not take place, and professional growth will be held to a minimum.

THE SUPERVISION OF THE SCIENCE PROGRAM*

National Society for the Study of Education

Supervision plays an extremely important role in any school organization. As the school system grows, specialists in science education are needed to provide for the constant growth and improvement in the science curriculum and instruction. This comprehensive discussion considers the various roles of the supervisor on the state, county, and local levels. The special problems that arise at each of these levels are presented, and suggestions are made as to how to meet these problems. This discussion is an excerpt from Chapter 12, "The Supervision of the Science Programs," of the Fifty-ninth Yearbook of the National Society for the Study of Education, Part I, Rethinking Science Education. Members of the committee who wrote this chapter include Donald Stotler, Lorenzo Lisonbee, Elra Palmer, Samuel Schenburger, and Henry Shannon.

THE NATURE AND IMPORTANCE OF SUPERVISION

Operational problems of one kind or another will quite certainly confront any established organization. If an organizational group is to remain dynamic, it must struggle toward equilibrium in structure at the very time that it is seeking ways to unbalance the equilibrium in order to improve the structure. This conflict between stability and change is blended most successfully in organizations where the expectancy is one of "structural mobility" or "organized change." In such situations the energy typically spent in resisting change is channeled into seeking and fostering types of change designed for the improvement of the whole organization.

The Need for Supervision

Supervisors are needed to help an organization live successfully as a "family" within its structural plan while at the same time helping to rebuild the structure. Doing this is difficult enough, but doing it with methods which permit acceptance of the supervisor as a member of the "family" is the acid test of modern supervision.

For this difficult role effective supervisors are in constant demand, for

* REPRINTED FROM *Rethinking Science Education*, 59th Yearbook of the National Society for the Study of Education, Part I (Chicago: University of Chicago Press, 1960), pp. 213-224, 226-228, by permission of the publisher.

the part they play in an organization is somewhat like the role of the catalyst in an organism. Membership in smaller educational organizations is often limited to planners (administrators) and teachers. Such an organization may be very successful; or it may result in the development of an arbitrary plan of action with little provision for reorganization and growth. More flexibility often results if the administrator provides some time for supervisory work or arranges to have a teacher released on a part-time basis for this type of service.

As a school system grows in size, both advantages and disadvantages emerge. One advantage arises from the fact that, between the administrative and the implemental levels, specialists in subject matter and methodology can be provided to play the catalytic role.

The Supervisor as a Consultant

When a supervisory program becomes more inhibiting than catalytic, the reasons are usually less obvious than those indicated in the preceding paragraphs. The latter may be only contributing influences. In an honest attempt to reduce friction and increase the effectiveness of a program, especially in larger systems, a stifling accumulation of rules, procedures, clearances, and general protocol may accrue. Out of this complexity may arise an atmosphere known in popular jargon as "bureaucratic." In this type of organization, the supervisor tends to become so preoccupied with procedure that proceedings grind to a snail's pace. It becomes so difficult or irritating to bring about change that initiative and creativity are stifled.

A new concept is arising in the field of supervision. In some systems the title of supervisor has actually been replaced by the title of consultant. Even where the title has been retained, the supervisor has become a consultant. The word itself denotes the change. A consultant is a person who is sought for suggestions and assistance in planning. The emphasis upon being sought is an invitation to initiative in others. It also means that to be successful a consultant must have something to offer in the way of knowledge and method.

Supervision: A Cooperative Endeavor

The modern concept of supervision is one of helping people help themselves. This is also the modern concept of classroom instruction. The supervisor is wise, therefore, to make all details of his approach consistent with the approach he advocates for teachers. If he believes teachers should set a wholesome emotional tone in the classroom, then he should seek a similar tone in the educational system. If he believes teachers should develop experimental-mindedness, curiosity, leadership, and self-analysis, he should seek to bring out these qualities in the adults with whom he works. If he believes that the teacher should use multiple approaches, employ diverse materials, encourage problem-exploration, and emphasize

individual differences, this belief should be reflected in his own activities.

All of this calls for that healthy give-and-take called cooperative planning. The supervisor by no means abdicates the role of leadership, nor does the classroom teacher who organizes the classroom in such a manner that she is freed to be a consultant. People seek the consultant in order to become oriented and to discuss new pursuits. The consultant, in approaching problems cooperatively, helps draw a larger circle with new problems. This may be an extension of a new interest or an enlargement of an old one, but it leads to a desire for leadership in opening up new frontiers.

Teachers may use the consultant approach with students, and consultants may use a similar approach with adult personnel within the educational system—and still the education of youth could be jeopardized if the community does not understand the modern approach. The supervisor uses the same approach with the community which he uses with the adult personnel in the school system and which he encourages teachers to use in the classroom. The attitude is not one of salesmanship of a finished program but cooperative problem-exploration in improving the program.

THE STATE CONSULTANT FOR SCIENCE

A typical state school system might have one thousand secondary schools in operation in one hundred fifty local school units. Each of these schools is an integral part of a complex machine devoted to the job of educating youth. If one were to evaluate the science programs in these schools, a normal distribution would probably be the result. The schools would vary in the effectiveness of their programs from very poor to very good, in much the same manner that members of a heterogeneous biology class would vary in their achievements. However, there would be many schools which failed to realize their potential and operated below their capacity, thus providing sufficient reason for initiating plans for improvement.

The Need for the Consultant

The state consultant for science occupies a unique and challenging position in programs for improvement. He works with all schools and with groups within the schools including administrators, teachers, pupils, and school boards. He endeavors to direct their energies into appropriate channels and to help them formulate plans of action for long-range improvement. He performs a motivating function, an analysis function, and a synthesizing function. The schools with weaker programs are encouraged to analyze their resources with the view of preparing a program which will raise the instruction to a higher level. Schools with

strong science programs are guided into well-planned experiments to discover more effective ways of handling the various aspects of the curriculum, and these are translated into procedures which can be used later by all schools.

The Role of the Consultant

The science consultant representing a state department of education will find himself involved in the thinking and other activities of many groups. He must work with all groups which are genuinely interested in providing the best scientific education for youth. With these groups his role will be that of a listener, an originator of ideas, a co-ordinator of activities, a procurer of help, and an encourager. In short, he will serve as the director of a team composed of many members, each of whom must be placed in the type of work which will assure the best results.

All of this means that the state consultant in science must know and understand the spectrum of science education in his state, which will include bases of the curriculum; relation of administration, teachers, and students to the program; physical facilities; experimentation; and new curriculum materials. When he finds there are gaps in this spectrum, he must work in such a manner that these voids are gradually filled. Unfortunately, this is an unending task for, as one gap is filled, another appears. Therefore, review of the spectrum and efforts to keep it unbroken must be continuous.

Responsibilities of the Consultant

As indicated in the preceding paragraph, the consultant, to be effective, must contribute to the achievement of the general goals by assisting in the solution of a variety of problems as they arise or become acute. A number of serious gaps have appeared in the science-education spectrum in recent years. One of these is the inadequacy of teaching personnel with respect to both numbers and training. This problem has arisen because of the upsurge in school enrollments, low salaries, poor working conditions, and the rapid change from an agricultural to a technological society. To make this situation more serious, the subject matter in the various science courses has necessarily undergone rapid change. Perhaps an answer is needed to the question, "What kind of program should be established to provide science teachers who will be able to channel the energies of youth into more productive efforts?"

The solution to this problem must be a co-operative affair, involving the science consultant, the state department of education, the colleges, the science teachers, administrators, and resource persons such as industrial chemists and conservationists. With the consultant as a co-ordinator, these groups can participate in science-teacher work conferences in local school systems and in programs on sectional and state levels. The work of these

conferences might be centered on such topics as the cell, the atom, photosynthesis, metabolism, chromatographic analysis, materials, and professional organizations. However, such conferences affect directly only those persons already teaching. Paralleling these activities must be others which deal with pre-service teacher education. With vitalized programs at the pre-service level, progress should be noticeable within a few years.

A second gap in the spectrum has occurred in the area of curriculum. The large volume of scientific information collected cannot be covered in the courses, and, as a result, important questions have been asked. What should be eliminated? What should be added? What sequence should be followed? What should be provided for the rapid learner? What background in science is needed by all citizens? These are only a few of many questions, most of which are difficult to resolve. Again, the science consultant is in a position to provide leadership in the development of good curriculum bulletins and in the planning of workshops and work conferences to attack these problems. But placing a bulletin in the hands of administrators and teachers will not insure beneficial changes. To accomplish needed changes, the science consultant must organize groups of teachers and selected consultants to develop the bulletin and then hold work conferences to study the finished product.

A third gap has occurred in the spectrum in regard to physical facilities for teaching science. The filling of this gap involves more than the provision of funds. A prerequisite is a clear understanding of the activities in which modern-day science students should engage and the type of facilities and equipment which will encourage the many aspects of problem-solving. In helping to fill this gap, the role of the consultant is obvious. He must present ideas to school personnel and architects and lend assistance in designing programs and facilities which reflect the best of available ideas.

Another responsibility of the science consultant is to provide the public with accurate information regarding the status of the science programs in the state. To do this effectively, he will find it necessary to collect and summarize pertinent data each year, and to make his findings available through the press, the radio, and television.

SUPERVISION AT THE COUNTY LEVEL

Harold Spears is quoted as authority for the statement that "The improvement of instruction for about half of the nation's school children is largely dependent upon the supervision that comes out of the office of the county superintendent."¹ He also reports that half of the counties do not employ supervisors, the superintendent carrying all supervisory responsibility.²

¹ Harold Spears, *Improving the Supervision of Instruction* (New York: Prentice-Hall, Inc., 1953), p. 235.

² *Ibid.*, p. 236.

In a survey of the 49 states made for this study,³ it was revealed that science supervision is, to the extent that it exists, provided by general supervisors or by the county superintendent. In some counties, certain county staff members with some competence in science education are employed. A few state departments reported that excellent work in science education was being done by these specialists. Leaders in a number of state departments reported a need for specialized supervisors at the county level, while others indicated a preference for general supervisors who would concentrate their efforts on teaching methods rather than on subject matter.

Special Problems

AT THE ELEMENTARY LEVEL. Replies to the questionnaire from the state departments can be summarized thus: (a) Elementary teachers, in the main, lack sufficient training in science and tend to shy away from science. (b) The combination of not having specially trained supervisors at the county level and not having classroom teachers trained in science renders unlikely any attempt on the part of the two groups to co-operate in the improvement of science education. (c) The lack of training indicated in (a) and (b) above is responsible, in large measure, for the lack of minimum physical facilities for a minimum program in science.

The consensus indicated that the first step in upgrading science-teaching in schools of the county is to obtain competent supervisors who have an interest in science and who would encourage the schools to employ science teachers who are competent and are interested in teaching science. This appears to be essential if children of high ability in science and mathematics are to be identified early and started on their way to science careers.

The Role of the County Consultant

Responses to the questionnaire from state departments gave general support to the idea that county consultants should be specialists in (a) supervision and curriculum, (b) the basic sciences, (c) methods of teaching science, and (d) human relations. The consultant is a resource person, ready to serve where and when needed. His association with teachers in the county should make them more confident of their ability to teach science. He is a leader in the broadest sense.

The science consultant provides liaison between teachers and administrators. He advises the superintendents and principals and reports to them on the progress and needs of the schools. He attempts to develop a unity of purpose among the schools of the county and co-ordinates the over-all effort from Kindergarten through Grade XII. He recognizes weaknesses in

³ In June 1958, an inquiry concerning the status of science supervision at the county level was mailed to all the state departments of education. There were 45 replies.

the programs of the schools and, in a democratic way, helps teachers and administrators correct them. He places proper emphasis on science instruction and assists in integrating science into the curriculum.

Responsibilities of the County Consultant

All of the science consultant's efforts are pointed toward upgrading science education in the county. He works constantly with teachers and administrators to improve instruction and to expand the opportunities afforded children for the study of science. He develops or assists in the development of a science program from the elementary grades through high school; helps develop programs of in-service training; trains teachers in methods of instruction, giving classroom assistance where needed and wanted. The consultant coordinates the county program as a whole and evaluates the curriculum in individual schools annually. He assists teachers and administrators in the reorganization of the curriculum and makes arrangements for institutes and workshops for the improvement of instruction.

SUPERVISION IN LARGE CITY SYSTEMS

The attributes of good supervision are the same regardless of the size of the school system; the problems involved, however, are of a different order of magnitude. The number and nature of opportunities for supervision differ from level to level and even at the same level. Although ideas do not easily flow among a large number of teachers, the existence of a large staff makes possible the addition of consultants, specialists, and supervisors with only a small percentage increase in the school budget.

Special Problems

AT THE ELEMENTARY LEVEL. The increase of dependence of our way of life upon scientific achievements has convinced educators that science must become an essential part of the elementary school curriculum. Elementary science is being increasingly introduced in many parts of the country, and the preparation of the elementary teachers to teach with confidence in that field is one of the primary aims of elementary education today. Since many school principals are not science specialists and many elementary teachers have little or no background in science, the problem of adequate supervision becomes a formidable one. A supervisor at the elementary level is called upon to perform many important functions. Among these the following are suggestive:

1. He must participate in the formulation of a science program which will explore scientific concepts and provide experiences for children from the Kindergarten through Grade XII.

2. He must participate in the preparation of resource publications which describe a variety of appropriate activities for implementing the science program.
3. He must engage in a broad teacher-training program designed to provide background and engage in workshop courses which will enable teachers to secure first-hand experiences with science subject matter, materials, and techniques.
4. He must recommend selections of supplies and equipment and proper procedures for obtaining them.
5. He must participate in the formulation of programs for talented students.
6. He must participate in the formulation of continuous in-service science programs which will supplement the initial background courses and workshops and will insure the professional growth of teachers throughout their teaching lifetime.
7. He must evaluate instruction through such methods as direct classroom visitations and follow-up conferences.

There are some elementary-science supervisors who are performing only part of the foregoing functions. In some cities some of these functions are being performed by science specialists. They are usually highly successful teachers with good backgrounds in science, who are freed from teaching to operate from a field superintendent's office. The specialists visit elementary school teachers in accordance with an arranged schedule or upon specific request of principals and teachers. The specialists can usually assist only in the performance of a few of the functions. They work with the teachers individually and in small groups. One consultant to every 120 to 150 elementary teachers is recommended.

The evaluation function, together with one or more of the other functions, is usually performed by the principal or assistant principal of the school. Either operates under a disadvantage when he attempts classroom supervision because his background in science may be too meager. Also, principals and assistant principals are so occupied with administrative duties and the entire program of elementary education that they are often unable to provide the leadership needed for science work at the elementary school level.

In this period of transition, when in-service science training of the present corps of elementary teachers is paramount, effective elementary supervision should remain the joint responsibility of the science specialist and the principal of the school.

To assure the proper supervision of classroom instruction and the professional growth of the elementary-school teachers, it is recommended by some that at least one person who possesses an adequate science background and supervisory training should be assigned to each elementary school. He would be responsible for the supervision of science instruction in addition to other duties.

Supervisors should not disregard the fact that the elementary and secondary schools are operating upon the *same* child at different stages of his development. Supervision on one level cannot, therefore, ignore the fields of science as they are explored on other levels if it is to assure the proper ordering of scientific concepts and activities for the maturing child. Thus vertical articulation, so obviously needed in our school systems, should be a prime responsibility of the science supervisor.

SUPERVISION IN SMALLER CITY AND SUBURBAN SYSTEMS

The large number of relatively small school systems in the country makes it necessary to study problems of supervision in such systems. Statistics indicate that 75 per cent of American high schools have enrollments of less than three hundred pupils, while 90 per cent have fewer than a thousand.

The Role of the Consultant

Supervision is an expert professional service which is primarily concerned with the improvement of learning. Thus, supervision deals with the improvement of the total teacher-learning process; orients learning and its improvement within the general aim of education; and co-ordinates, stimulates, and directs the growth of teachers through co-operative leadership. It is deeply concerned with the long-range improvement of science education.

To accomplish these aims and those stated in the first part of this chapter, the supervisor or consultant offers such services as:

1. Developing in-service educational programs.
2. Developing a science curriculum.
3. Visiting classrooms.
4. Establishing and implementing educational goals.
5. Planning demonstration lessons.
6. Coordinating services.
7. Suggesting and supplying resource materials.
8. Helping in the selection and purchase of textbooks and equipment.

The supervisor or consultant also has obligations to raise professional standards, build teacher morale, serve as a resource person, encourage advanced study and research, and interpret the science program to the staff and the community.

One of the major advantages that the science consultant in smaller cities has is the opportunity to know his teachers well and to recognize their strengths and weaknesses. The possibility of developing an exceptional *esprit de corps* is greater than in the larger cities.

Providing for Adequate Supervision

In this period of increasing emphasis upon science education, it is imperative that small city and suburban systems provide adequate science supervisory service. It is a prime factor in the improvement of science instruction.

Wherever feasible, a full-time science consultant should be employed to assist with the program in Grades I through XII. In those cities of approximately 200,000, an assistant may be employed who is a specialist in the field of elementary science. In small districts science leadership can be provided by the head of the school science department. This individual should be given adequate time and compensation for performing the services needed to facilitate an on-going science program.

Within the framework of the American philosophy of education, the schools belong to the people. The schools reflect this concept, and, therefore, will generally be only as good as the citizenry demands.

General Qualifications of the Science Consultant

The science consultant should have a thorough subject-matter background, a basic knowledge in the major branches of science and their interrelationship. In addition to the subject-matter qualifications, the consultant should have professional training in supervision and administration. It is important that the supervisor be familiar with recent developments in the fields of science and education. The consultant certainly must qualify as a superior teacher and should have at least five years of successful teaching experience in the grade levels concerned. It is unrealistic to require previous experience in science supervision since such a small percentage of the school systems, up to the present time, have employed science consultants. A lack of experience in supervision may well be offset by experience within a school system. One of the most important competencies lies in the field of personality. The consultant must be able to work well with his peer group and possess a deep insight into the problems of human relations. He must establish rapport with his teachers in order to carry on free and frank discussions. He must have the ability to assume a leadership role. He should bring to the position a high degree of imagination and creativity. He should be able to recognize the need for specific kinds of help—corrective, preventive, constructive, and creative. He should possess a sense of humor and the maturity to accept decisions adverse to those he has made or would make. These traits and abilities may well serve as guideposts for the selection of a consultant, and it is hoped that they will develop more fully with experience on the job.

IMPROVING THE EDUCATION OF THE SCIENCE SUPERVISOR*

J. Darrell Barnard

J. Darrell Barnard defines the qualities that make a good science supervisor. He groups these qualities into two categories. First, there are attributes, which refer to those qualities that one innately possesses or comes to possess by processes not clearly revealed. Second, there are competencies, which refer to those qualities that one learns or may learn as a part of his professional education or experiences. Dr. Barnard lists ten attributes and sixteen competencies, which should become the goals of a graduate program for the education of science supervisors.

It seems reasonable to begin an exploration of this topic by asking the question: What is a science supervisor? The question can be asked but there is no simple answer. Based upon the findings of his survey of the science supervisor, Ploutz concludes, "Due to differing conditions within school systems throughout the United States, there is probably no such thing as *the model supervisor*."¹ Among the 100 supervisors of science included in his study, he found four different models. There was the K-8 or elementary school model; the 9-12 or secondary school model; the K-12 or total curriculum model; and finally the state department model. He also found a variety of titles given to persons who assumed a science supervisory role in schools: science-helping teacher, science-resource person, science consultant, and science coordinator. We could add others such as departmental chairman and director of science.

It is my understanding that NSSA has had a commission working upon the problem of defining a science supervisor model based upon the duties he should properly perform. Until such a time as the NSSA model has been developed, we shall have to resort to our own definitions. For purposes of this paper a science supervisor is any one in a school system who has been trained in science education and who, because of this training, has been given official responsibility for the management of all or

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¹ Ploutz, Paul F. "Survey of the Science Supervisor," *The Science Teacher* 28: p. 411 (October 1961).

some part of the science program, beyond the specific science courses that he teaches. He may assume this responsibility on a full or part-time work schedule. I realize that this is a broad definition, but so is the present status of science supervision in the schools. A part of this might be accounted for by the fact that little distinction has been made between the education of the science teacher and the science supervisor. I am hopeful that this paper may help to clarify some of the confusion—not compound it further.

Working within this rather nebulous concept of the science supervisor, I have attempted to define qualities that go to make a good one. In part this has been done by making case studies of some science supervisors as I have come to know them and their work. The remaining qualities have been identified by analyzing duty lists for supervisors prepared by school administrators, teachers (both the beginning teacher and the experienced one), and by supervisors themselves. I have divided my items of quality into two categories. For want of a better term, I refer to my first category as *attributes* and to my second category as *competencies*. As you can predict, the distinction between these two categories is a relatively tenuous one. *Attributes* refer to those qualities that one innately possesses or comes to possess by processes not clearly revealed. *Competencies* are those qualities that one learns or may learn as a part of his professional education or experience.

None of the persons included in my case studies arrived at his position as a supervisor by satisfactorily completing a collegiate program specifically designed to educate him for his position as a supervisor. Excluding school systems where qualifying or licensing examinations are required, there are probably as many ways to become a science supervisor as there are science supervisors. Be that as it may, I have found what appears to be certain common prerequisite qualities possessed by my subjects.

Some time prior to being made a supervisor, they had demonstrated that they were "good" science teachers. (I have put good in quotes because this may mean slightly different things to different evaluators.) Second, they had identified themselves as "leaders" among their peers. (Again I have put leaders in quotes for much the same reason.) Third, they were not satisfied with models of science teaching as they had observed them. Fourth, they had "ideas." These included ideas about improved models of science teaching. Fifth, they were "aggressive." I do not mean aggressive in a derogatory sense, but in the sense they moved out to get things done.

The above are five attributes generally shared by my subjects. However, there are five other attributes that are possessed in varying degrees by different subjects. And yet they appear to be qualities of a high order of importance in becoming a good supervisor. They include modesty, adaptability, critical mindedness, a well developed system of values, and respect for the worth and dignity of each teacher with whom he works.

For the most part these qualities are beyond the purview of formal

education. Or to put it another way, if the prospective candidate for a supervisory position does not possess a good proportion of these qualities, not much more can be done to help him become a supervisor. It would seem that these attributes represent a basic list of qualities which one should possess before he is admitted into a graduate program for science supervisors. How to determine their possession becomes a perplexing admissions problem.

As I mentioned before, the second list of qualities represents competencies, or "abilities to do," which to a large extent can be developed, in fact, they should become the goals of a graduate program to educate science supervisors. I hold no brief for the completeness of this list, however, I do consider the 16 listed here to be important ones based upon analyses of the various lists of duties:

1. He should be able to envision the essential features of an articulated K-12 science sequence. This does not mean that he should have a neat little K-12 package worked out on paper or in the head. But he should be able to tell what the principal features of a good one would be, and therefore to provide leadership in developing one or in evaluating "ready-made" packages that may be available to schools.

2. He should be able to innovate and objectively to evaluate the innovations of others as they relate to methods, content, equipment and sequences. This would mean that he has developed a rational frame of reference, philosophically and psychologically, which he consistently applies in evaluating "new" ideas.

3. He should be able to distinguish clearly between effective and ineffective teaching practices and to rationalize the bases for the distinctions he makes. He must be more than an intuitive evaluator of teaching.

4. He should be able to motivate teachers to seek means of improving their practices and to counsel them regarding effective ways of going about it.

5. He should be able to use effective procedures for evaluating the progress of students, as well as the effectiveness of teachers in directing the learning experiences of students.

6. He should be able to design and conduct investigations that will yield reliable evidence regarding the effectiveness of instructional programs.

7. He should be able to interpret science education, in general, and his school's science program, in particular, to other educators and to laymen in the school community.

8. He should be able to design and administer inventory systems and prepare defensible budgets for the procurement and proper maintenance of science materials and equipment.

9. He should be able to initiate and direct in-service science curriculum studies and workshops or institutes for upgrading and updating science teachers.

10. He should be able to keep teachers informed regarding current developments in science education and promising innovations in science teaching.

11. He should be able to demonstrate effective ways of teaching for the various outcomes, especially the less tangible ones such as critical thinking.

12. He should be able to adapt his method of working with teachers to the idiosyncrasies of teachers. Teaching is basically a personal accomplishment. He should not only accept it as such, but strive to get teachers to do so.

13. He should be able to *listen* to teachers and to gain insights regarding their points of view, their aspirations, their frustrations, their fears and their needs. Just as a good teacher listens more than he talks, so should a supervisor.

14. He should be able to identify the strengths and weaknesses of individual teachers and to help each teacher overcome his weakness without depreciating the teacher's self-image.

15. He should be able to conduct group conferences and work sessions in ways that maximize the contributions of participants.

16. He should be able to help teachers understand the objectives of science teaching in terms of their consequent behaviors. He should be able to operationalize objectives.

The above list of 16 competencies, supplemented by the 10 attributes mentioned earlier, should provide basis for thinking about ways in which the education of supervisors might be improved.

It would seem that we begin with the assumption that one who would become a supervisor must first have been a teacher. Next, we assume that all science teachers will not or should not become supervisors; that the prerequisites for becoming a supervisor involve something more than being a teacher. Finally, we assume that the education of science supervisors is a joint responsibility of public school systems and collegiate institutions. Just what the relative roles of each should be have not been clearly delineated. In fact, I am hopeful that the remainder of this paper might throw some light upon the subject.

There is a pre-service and an in-service phase to the education of science supervisors. The in-service phase has to do with those who are practicing the profession of supervision. The pre-service phase has to do with those who seek to prepare themselves to be supervisors.

What has been the pre-service education of supervisors? Most of those in supervisory positions began their careers as secondary school science teachers. Their academic preparation was basically that required to be certified as secondary school science teachers. Their science content courses were those that were assumed to prepare them to be either chemistry, physics, earth science, or biology teachers. Outside of the foundations courses in philosophy of education, history of education and/or educational sociology, their professional courses were geared to the

secondary level: principles of secondary education, general methods of teaching at the secondary level, methods of teaching secondary school science, and adolescent psychology. Pre-student teaching observation and student teaching were limited to secondary schools. In other words, their orientation was almost exclusively secondary, which represents only the upper half of the K-12 science sequence. I do not believe that this pattern is adequate either for the secondary school science teacher or for the prospective science supervisor.

How should the pre-service education of prospective science supervisors be improved? The content background required to be competent science supervisors, precludes prospective candidates coming to such positions through the elementary school. Most will continue to enter supervision by way of the secondary-school-science-teacher route. Secondary school science teachers know relatively little about elementary education, and more specifically about elementary school science. In part, this accounts for some of the difficulties which schools encounter in their efforts to develop K-12 articulated programs in science. Why shouldn't secondary school science teachers be more knowledgeable in elementary education? I believe they should and propose the following changes in the professional courses which they are required to take in preparation for teaching at the secondary school level.

Instead of a course in principles of secondary education, I would propose a course in principles of education. In this course the principles would be applied to both elementary and secondary education. Instead of a course in adolescent psychology, they should have one or more courses that deal with growth and development from 5 years to 17 years of age. The concepts of growth and development as they relate to learning should be high-lighted. The general methods of teaching at the secondary school level would become a general methods course for teaching at both the elementary and secondary school level. The science methods courses would deal with methods of teaching science at the various grade levels. Pre-student teaching observation would include observation in both elementary and secondary schools. Student teaching would be done at both levels.

The implementation of such a proposal calls for some radical changes in our colleges of education where specialization in elementary and secondary education has become unreasonably entrenched. In spite of the tenability of assumptions underlying such a proposal, the specialists in elementary education and the specialists in secondary education will probably contend that such courses cannot be taught within the conventional limitation of credits allocated for professional courses. After some radical surgery of present courses, I believe they could.

With this broad-based background in elementary and secondary education, secondary school science teachers should be much better equipped to perform their duties within a K-12 science sequence.

Furthermore, the potential pool of candidates for supervisory positions in science at the various levels will become enlarged.

It would seem to me that science teachers who aspire to prepare themselves for supervisory positions should have taught a minimum of five years. They should have had experience at the elementary, junior high school and senior high school levels. They should take at least one year of graduate study beyond the masters. Whether the advanced work is recognized academically by a sixth-year certificate or applied toward a doctorate, it should be designed to accomplish the following:

1. Bring the candidate's science background up to a minimum of 18 points in graduate courses. (6)
2. Provide an internship in supervision for at least one semester. (6)
3. Include a full-year practicum to deal with such topics as: (6)
 - a. The K-12 science sequence.
 - b. Innovations in science teaching.
 - c. Evaluation of teaching practices.
 - d. Objectives as behavioral goals.
 - e. Demonstration teaching.
 - f. Adapting methods of supervision to the idiosyncrasies of schools and teachers.
 - g. How to listen to teachers.
4. Include these courses:
 - a. Research design and statistics. (6)
 - b. Tests and measurements. (3)
 - c. Group dynamics. (3)

Let's look next at the in-service phase of the supervisor's education. Except in large school systems, the science supervisor finds few professional associates within the system who share his specific interests and problems. In various ways he may become associated with supervisors of other subject fields when general problems of supervision are considered, and this can make an important contribution to his education as a science supervisor. Through membership in NSSA, he may become involved in conferences and clinics dealing with problems of the science supervisor. He may read the professional literature and even contribute articles. He may have the good fortune of working with a group of science teachers who stimulate him to push out beyond the fringes of established routines. From time to time he may even seek assistance with certain problems from the professors in nearby collegiate institutions. He may spend all or part of several summers at institutes and work conferences for supervisors. He may have the privilege of working on one of the course improvement projects. Along the way he may even complete his doctorate in science education and thereby earn his union card. Through these and other self-initiated activities, he provides for his in-service education as a

science supervisor. My guess is that the above is representative of the logs of many of the supervisors attending this conference. Does the procedure need to be improved? If so, should collegiate institutions become more actively involved?

Collegiate institutions have three major responsibilities: 1) Inquiry; 2) Instruction; and 3) Service. There are two of these that have particular implications for improving the in-service education of science supervisors.

Some institutions have distinguished themselves for the consultant services which their professors have provided to schools. In fact, the demands from schools for such services have often diverted professors from their more fundamental responsibility, inquiry. Professors have rationalized their neglect of research by citing their busy consultation schedules and contending that the feed-back from this effort is helping to advance knowledge in science education. Except in those institutions, such as Florida State University, where the service to the schools is one of conducting formal inquiry into teaching problems on a cooperative basis, such contentions of productive feed-back are largely wishful thinking.

If institutions were to limit their school services to cooperative research projects, both schools and institutions would profit. Schools would profit through the involvement of its supervisory staff and its teachers in research, as well as getting more definitive answers to many of their questions. The collegiate institution would profit through the redirection of its energy into channels that are more traditionally the responsibility of the university, a fundamental responsibility not generally assumed by any other institution in our society.

In terms of their professional performance, supervisors share with many college professors a critical deficiency. Few, if any of them, are actively involved in research designed to advance our understanding of problems related to science teaching. It is toward the correction of this situation that collegiate institutions could contribute most to the improvement of the in-service education of science supervisors and to the upgrading of its own contributions to the profession.

If the research is to be cooperative it should deal with unresolved problems faced by the schools in their efforts to advance science teaching. The processes involved in the identification of these problems and in asking the questions that should, and can, be researched not only represents a real challenge to the schools but will also require the best research talents that collegiate institutions can provide.

It is unreasonable to assume that sustained cooperative research efforts of any significance will be accomplished by forcing supervisors and/or professors to become involved. The consequences of such "forced feeding" is that as soon as the pressure is removed, the research effort terminates. For example, how many of those who were "forced" to do research in fulfilling their requirements for the doctorate have continued to be active in research? It would seem that the one-shot deal immunizes against further research rather than spreads the infection.

Somehow we need to develop a climate in which we habitually turn to research for answers to the many unresolved and critical questions that face us in science education. Many of the persistent problems in science education result from practices based upon *superstitious* beliefs and *pedagogical folklore*.

In our efforts to change the intellectual climate of science education we should begin with the research that has been done. I cannot agree with those who contend that most, if not all, of the research in science education is worthless. For 25 years prior to the recent efforts to improve science curriculums we had evidence that something was wrong. Furthermore, there was abundant evidence from the research that the teaching methods so commonly practiced were not only ineffective, but actually deleterious. But it was not until the scientists intuitively arrived at this conclusion that it was given effective visibility. And they have had their problems in convincing some teachers whose behavior has been guided by superstitious beliefs and the folklore of science teaching.

In professional courses for science teachers and supervisors, research findings should be used in dealing with the basic questions of what, how, and why. Where the findings from research are not adequate, it should be clearly indicated that we tentatively rely upon best judgments. Teachers, supervisors, and professors should become conditioned to distinguish between fact and opinion in dealing with curriculum problems in science. We should adopt the attitude of Dr. Anton J. Carlson, the distinguished physiologist, who became a thorn in the side of many a glib physiologist by repeatedly asking the question: What is your evidence? But Dr. Carlson did not merely ask the question. Where there was no evidence, he set about to find it. This led to many of his classical experiments on the physiology of hunger and digestion. Furthermore, his book, *The Machinery of the Body*, is an exemplary physiology text in which the concepts of physiology are largely taught by reviewing the research that led to them.

Why, in the community of science educators, is there not a greater professional interest with opinions lacking the support of evidence? Is it because we have become enamored with the doctrine of expediency? Is it because we are unwilling to subject ourselves to the discipline required of him who would search for evidence? Is it because the profession and the public put higher premiums upon other kinds of performance, such as attending conferences, conducting institutes, developing "new" curriculums, making speeches, and writing textbooks? Is it because our "busy" schedules allow no time for the reflective thinking, reading and probing that is required to get started?

Money buys time and increasing amounts of money are becoming available to buy a part of the time of those qualified persons who would commit themselves to do research. In our own institution, released time from one or more classes is now given to professors who wish time to design investigations. Funds are also available for travel and consultant

assistance. I imagine that our institution is not unique in this respect; that other institutions are also developing climates that are conducive to the spawning of a greater research effort in science education. As this becomes more of a way of academic life at institutions where supervisors and potential supervisors obtain their training, there will be more research infections and fewer research immunizations.

If I seem to have overemphasized involvement in cooperative research as an approach to the improvement of the in-service education of science supervisors, it is because I strongly believe that it is the most neglected aspect of our efforts to advance professionally. If more of it were being done, conventions such as this one might become disturbing, enlightening, dynamic forums rather than polite gatherings for purposes of listening to rehashes of ideas such as those presented in this paper.

THE PRINCIPAL'S ROLE IN THE ELEMENTARY SCIENCE PROGRAM*

Paul F. Ploutz

Paul F. Ploutz discusses the importance of the principal's role in establishing a good science program in the elementary school. The principal, as the instructional leader, should provide the necessary stimulation to increase the effectiveness of the science program. Dr. Ploutz provides a twenty-question check list for self-assessment by elementary school principals. The check list can identify areas of weakness where the principal is failing to provide the kind of leadership that he alone can provide. Dr. Ploutz also outlines five desirable areas for involving the teacher in the development of a good science program.

Elementary teachers have frequently been blamed for dereliction of duty in teaching science.

Colleges of education have been accused of granting elementary teaching certificates to those who "didn't like" or to those "afraid" of science.

Personnel and employment directors for public school systems ask the routine questions when interviewing teacher candidates but avoid

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questions relating to science. When "you need teachers," you don't scare candidates with science questions.

As for science supervision and in-service education, a recent study revealed that even "elementary supervisors of science have less authority, status, experience, assistance or training than other groups of supervisors."¹

In one report or another virtually everyone from the Board of Education to the kindergarten child has been charged with neglect in the elementary science program. In all probability, the reason different groups have been charged with neglect hinges on the fact that a good curriculum is a result of effort by many people. The failure of a science program to meet existing needs is conversely apt to be a neglect by many.

As the instructional leader, the elementary principal can and should be the key person in stimulating teachers and other administrators in recognizing and implementing an elementary science program that has previously stalled in passive indifference, lack of funds, or out-dated concepts of the importance of science in our way of life.

It is the purpose of this article to assist the elementary principal in appraising the need for increased (1) physical facilities, (2) science apparatus, equipment and materials, and (3) student science activities in his school. The need for science equipment at the elementary level continues to keep many experiments and demonstrations from taking place. Insufficient equipment limits the effect of in-service education efforts for both new and experienced teachers. In many instances, new equipment can be used to motivate teacher interest in science. While it is generally conceded that many elementary teachers either partially or wholly neglect science, the science equipment situation in many instances is even worse. A strong case can be made for the fact that the present importance of science is so immense that elementary schools, virtually without exception, do not prepare their students with science concepts and understandings necessary for the present, much less future anticipated needs.

Many elementary children with interest and ability in science get more science instruction in their out-of-school environment than at school. It is still commonplace to find fifth or sixth grade students constructing or owning crystal radio sets, transistor radio sets, microscopes, and the like; while the school they attend owns less equipment than the children.

Elementary principals are frequently aware that the students in their buildings are "pushing" the teachers in the area of science—not an impressive situation from an administrative or Board of Education viewpoint. Even in those situations where the school board and administration provide sufficient leadership, there is a lot of time, training, and money involved between recognizing the importance of science and implementing an acceptable elementary science program.

¹ Paul F. Ploutz, "The Science Supervisor," unpublished Field Study Number 1, Colorado State College, Greeley, Colorado, May 1960.

School systems have, to varying degrees, recognized the urgency for elementary science, yet many have done very little other than stating the need. In respect to personnel and finances required for a modern-day program, some school systems have made little, if any, progress.

While we legitimately continue to emphasize the importance of science to elementary teachers, have we provided equipment necessary to implement the program? In the face of the financial squeeze and budget reductions in which 23 per cent of all 1960 public school bond issues in the United States failed at the polls,² have we rationalized our thinking into believing that string, milk cartons, and balloons can replace a microscope, tuning fork, and aquarium? Has the over-worn concept of homemade gadgetry, coupled with slogans of teacher inventiveness and creativity, sold principals into thinking that teachers can teach science without equipment?

In a mid-western state where teachers' salaries and the educational tax base are well above the national average, this writer recently visited a well-known system noted for high standards and excellence. It was discovered that of the twenty-six elementary schools involved, eighteen had less than \$150 worth of science equipment per school. While this particular community had demonstrated its continued desire to have and support superior programs, the elementary science program was based on an inaccurate curriculum guide prepared by teachers. The teaching, or lack of teaching science in the schools was left to the whims or strengths of twenty-six principals working individually. There were no budget provisions for science equipment; in-service education consisted of an occasional college extension course accommodating only twenty or twenty-five of the 600+ elementary teachers in the system. In those few schools where the elementary principal had an interest or a college minor in science, the science activities in the school were clearly evident. In these situations, the elementary principal was the instructional leader in reality, rather than in theory.

It seems increasingly obvious that while many factors are in play in determining the nature and caliber of a good science program, the role of the elementary principal is *singularly* important.

The likelihood of having a good elementary science program in a school where the principal is not active and interested in science activities is obviously not good.

But what of NDEA?³ Have elementary principals made themselves aware of how NDEA funds are secured and been aggressive in pursuing their needs? Perhaps with the secondary schools adding courses in earth science, electronics, and biology, and "beefing up" general science, the secondary program has absorbed most of the funds available. Perhaps,

² *Phi Delta Kappan*, Vol. XLIII, No. 2, November 1961, p. 53.

³ National Defense Education Act, Title III (passed September 1958, providing federal funds for science, mathematics and foreign languages; effective until 1964).

however, the elementary principal has not made his "pitch." There is no controversy in the need for outfitting newly constructed and existing secondary science facilities. The question may well be, however, have NDEA funds passed by the elementary school by default?

The following check list is designed to assist in identifying those ways in which the principal, as instructional leader, can work to increase the effectiveness of the elementary science program in his building or in his system.

CHECK LIST FOR ELEMENTARY PRINCIPALS⁴

1. Have you informed yourself how much money your system obtains through NDEA?
2. Do you feel the elementary schools receive financial assistance reasonably proportionate to what secondary schools are securing through NDEA?
3. Have you identified one, two, or more teachers in your school to put on building science workshops or promote science activities?
4. Have you encouraged teachers to report their science equipment and material needs to you?
5. Do you develop an equipment-needs list during the school year for inclusion on budget for the following year?
6. Are there provisions for ordering small amounts of simple chemicals and expendable materials *during* the year?
7. Does your library meet American Library Association standards and subscribe to science reference books and magazines for both teachers and pupils?
8. Is your library securing many of the new science and mathematics books prepared for children?
9. Do you have, or have you considered forming, a science club in your school?
10. Has your school taken advantage of streams, planetariums, industry, and other field trip resources in your area?
11. Do you keep your teachers aware of science films available in various areas of science? (Astronomy—"How Many Stars," Moody Institute of Science, et al.)
12. Are your teachers convinced that *you* consider science important?
13. Do you encourage science displays, bulletin boards, collections, etc., in halls, library, or other places in school buildings?
14. Are you aware and have you informed your teachers of the professional organizations related to elementary science?
15. Are science concepts presented and expanded upon in a grade-to-grade sequential manner?

⁴ A three-column check space with captions "Yes," "No," or "Don't Know" was placed to the right of the questions. Deleted here for space reasons.

16. Do you involve the P.T.A. and related groups in the school science program through a school fair and student science display; and have you encouraged or supported Boy Scouts, 4-H Clubs, Brownies, and other groups interested in science?
17. Is the copyright date on every science textbook now in use less than five years old?
18. Are proper storage facilities available with easy teacher-access to science equipment?
19. Does every teacher have access to projectors, film strip machines, and other audio-visual aids in classrooms which may be easily darkened for audio-visual and demonstration purposes?
20. Does each teacher have some facility for a science table, corner aquarium, hobby display, science materials shelf, stand, or table?

Twenty "Yes" answers could be considered ideal.

Six or more negative answers should offer stimulation.

The preceding check list can identify areas of weakness existing systemwide or in only one elementary school.

It is recognized that involvement is one of the keys to creating interest and affecting change in students' behavior. The technique for teachers is the same.

In developing an elementary science program, it is desirable, when possible, to involve the teacher in:

1. Selecting the content and concepts to be presented at each sequential grade level.
2. Determining what experience seems most effective in children's learning concepts from grade-to-grade.
3. Determining what equipment is needed to teach concepts selected in the K-6 program.
4. Organizing an in-service education program around need for all science content areas as well as most effective utilization of equipment.
5. The evaluation of the effectiveness of the total K-6 instructional program in science.

Since many elementary science programs are ineffectual or generally inadequate in emphasis, rather than non-existent, the problem is generally more often one of "stimulating" an existing program, rather than creating a totally new program.

The elementary principal must now, more than ever before, assure each student the opportunity to develop his potential in science.

"Though only a few students will ever become research scientists, local schools still hold the great responsibility of providing an up-to-date

science program, continuous from the kindergarten through the twelfth grade, to provide the academic atmosphere that will allow certain students to greatly excel.”⁵

We need only to further encourage and develop the existing inborn natural qualities of curiosity in children. Our country is in great need of scientists in every field. It is equally true that we need statesmen as much as physicians, missionaries, and technicians.

The elementary principal must accept his tremendous share of the responsibility that future generations do not run out of top soil, or starve in attempting to feed the overwhelming population increase. The boys and girls in today's elementary schools must prevent us from smothering in smog or losing the battle with the bugs. The youth of today must soon mend our hearts and cure our cancers. The one question keeps returning, however: are we doing enough in science to prepare them for the challenge immediately ahead?

⁵ Paul F. Ploutz, "The Science Supervisor," unpublished Field Study Number 1, Colorado State College, Greeley, Colorado, May 1960, p. 115.

SCIENCE IN THE ELEMENTARY SCHOOL: AN NSTA APPROACH*

Glenn O. Blough

Dr. Blough describes the contributions which the National Science Teachers Association, since its inception in 1944, has made to elementary science teaching. He also lists the various services available to elementary school teachers through NSTA membership—a magazine, a variety of publications, and national and regional meetings and conferences. He looks to the future and speculates about the direction elementary school science learning will take in the next ten years.

Since its inception in 1944, the National Science Teachers Association has emphasized that science teaching begins at the Kindergarten level (or earlier) and ends—well, ends wherever science teaching and learning end.

* REPRINTED FROM *Science and Children*, Vol. 6, No. 3, November 1968, pp. 24-26. Copyright, 1968, by the National Science Teachers Association, Washington, D.C. Reprinted by permission of the author and the publisher. Dr. Blough is Professor of Education at the University of Maryland.

The Association has stressed this point of view and each year has widened its influence through its increasing membership and services to all teachers of science.

NSTA has made significant contributions to the growth of science teaching in the elementary school. In fact, the field of elementary science has itself sprinted, indeed raced, ahead and can scarcely be recognized as the one that the executive secretary was thinking of years ago when he said, "We ought to do more to help all those elementary teachers who wish they were doing better science teaching."

In considering the vast number of elementary teachers, the Association has realized from the beginning that they vary greatly in their science background, interest in science, and ability to teach it. The great gap continues - all the way from a teacher who is almost afraid of a dry cell to one who will build his whole curriculum around science activities. The amount of assistance available to teachers varies almost as much. Some teachers must rely on their own initiative to improve, while others work in an environment teeming with help for the asking.

What kinds of help can an association offer under these conditions? It can produce reading material, hoping that it will reach those who need it and that it will be appropriate and helpful. It can provide speakers, panels, symposia, and so on, at its many meetings that will attract and assist elementary teachers. It can sponsor conferences designed especially to explore problems and solutions in science at the elementary level. At these meetings, participants have personal contact with leaders in the field, discuss and compare guidelines, review teaching standards, peruse new materials, and generally grow professionally. Each year the Association has continued to expand its efforts along these avenues, always revising its offerings on the basis of what it can learn about their effectiveness from teachers and others.

In recognition of the special needs of teachers in elementary schools, the Association has designed special membership services. At present the elementary teachers who join the Association as Elementary Members receive a year's subscription to *Science and Children*, are kept informed of national and regional meetings (which they are urged to attend and participate in), learn about new publications appropriate for them, and enjoy full rights and privileges in the Association. Elementary Membership in NSTA is available to all persons engaged in or interested in elementary education.

MAGAZINES

At the outset of the Association, *The Science Teacher* included in each issue material helpful to elementary teachers. But soon the Association faced the fact that this publication could not spread itself enough to do justice to all levels of science teaching—secondary, collegiate, and

elementary. To continue help to elementary school teachers, the first issue of the *Elementary School Science Bulletin* was published in May 1952. This four-page publication contained articles about science subject matter and methods of teaching, notations about books and materials, and meeting announcements. *ESSB* caught on at once and grew to 12 pages and a circulation of 40,000.

Although the *ESSB* was a success to its readers, it wobbled along chiefly with the help of a volunteer crew scattered in teaching institutions around the country and the "spare" time of NSTA office personnel. Eventually, the increased emphasis on teaching science in the elementary school pointed to the need for a more substantial publication, and in September 1963, *Science and Children* came into being—an over 40-page magazine with editors, other assistance from the NSTA office, an advisory board, a group of scientists to act as technical consultants, and a budget. Here at last was a publication devoted specifically to the teaching of science in the elementary school. Now in its sixth year, it reaches over 30,000 teachers with articles, book reviews, important announcements, special features such as reviews of materials, and short descriptions of successful science teaching practices of and by its readers. Commercial advertisers in *Science and Children* inform teachers of the materials available for science teaching. Scientists, teachers, supervisors, college and university personnel, photographers, and others regularly contribute to *Science and Children*.

Examine the various issues of *Science and Children*, and you will see that many of the innovative practices reported have come when scientists, psychologists, and educators have worked together—each contributing his special talent. In many instances NSTA led in sponsoring such coalition, and it will continue to do so.

MEETINGS AND CONFERENCES

The amount of time devoted at the annual and regional meetings of NSTA to science in the elementary school has increased with the interest and need. Here elementary teachers have been able to meet and hear the outstanding educators in elementary school science, participate in panels and symposia, attend seminars, see the latest in books and materials at vast exhibits, and get acquainted with others with similar interests and problems. Each year the number of elementary school teachers attending these meetings has increased. As an example of the opportunities afforded elementary teachers, a recent annual meeting provided opportunities to hear and participate in programs on educational TV in science; the new science curriculum programs; effective inservice programs; physics, chemistry, earth science, and biology seminars; theory of learning; teaching techniques; and communication and transportation workshops.

The Association also sponsors ten or more regional conferences each year throughout the United States. Each of these meetings provides a

portion of the program especially for elementary teachers. NSTA's Saturday Science Seminars also offer elementary teachers of science access to resources, information opportunities, and services during one-day workshop programs.

In addition to the annual and regional meetings, the Association has long sponsored special conferences. A particularly productive one, in 1958, was supported by funds from the National Science Foundation. About thirty-five of the most knowledgeable educators—school superintendents, science supervisors, principals, science consultants, teachers, and others—participated in that conference to develop promising recommendations and actions for extending and strengthening programs of science in the elementary school. As a result of these deliberations, a publication, *It's Time for Better Elementary School Science* (1),† was prepared. Its recommendations have had wide influence on plans and practices in such areas as elementary school science programs, improving the curriculum and teaching methods, inservice education, preservice programs, and materials.

Further contributions to the field have been made by the Association through its interest in curriculum building and evaluation. *Theory Into Action* (6), a publication which resulted from the work of an NSTA curriculum committee, has had a strong influence in establishing criteria for sound curriculum development.

In 1961, NSTA added the position of a specialist in elementary science to the headquarters staff. This individual fulfills the role of consultant to special projects and programs, and acts as a liaison between other education organizations—in particular, the growing number of elementary school science associations around the country. Presently, there are three of these groups that are affiliates of NSTA (the Elementary School Science Associations of Northern and Southern California and the Elementary School Science Association of New York). These associations hold their own annual conferences and seasonal workshops.

OTHER PUBLICATIONS AND SERVICES

In response to requests for more specific teaching suggestions, the Association planned and has published several items in a continuing series of instructional aids, the "How-to-do-it" publications. Titles include *How to Care for Living Things in the Classroom*, *How to Evaluate Science Learning*, *How to Record and Use Data* (4), and others. These are mainly aimed at elementary school teachers who want to improve their teaching and need a clear, concise treatment of a specific problem.

To help meet the needs of teachers who lack a good background in science subject matter, along with hints for teaching it, the Association

† See Bibliography.

has produced a series of six books titled *Investigating Science with Children* (5). Thousands of teachers have learned to teach more effectively through using these publications. They meet the needs of the beginning as well as the experienced teacher.

In 1950-51, NSTA produced a series of seven booklets by Guy V. Bruce called *Science Teaching Today*, which included demonstrations and projects on air, water, heat, sound, etc. The series was one of NSTA's early bestsellers, with five editions printed.

As a service to elementary teachers who "can't find the issue that had that article about . . .," the Association decided to select some of the most significant articles from the first three years of publication of *Science and Children* and combine the collection into a single volume, *Helping Children Learn Science* (3)—a compact source of information describing objectives for elementary school science, background information, resources for teaching and learning, classroom ideas, and strategies for now and the future.

COUNCIL ON ELEMENTARY SCIENCE INTERNATIONAL

In 1920, the National Council of Garden Teachers was organized. In 1930, this group was renamed the National Council of Supervisors of Elementary Science, and eventually in 1963 became the Council on Elementary Science International (CESI). CESI was supported by many of the same educators who were also involved in activities of the National Science Teachers Association. Its chief contributions were sponsoring meetings in conjunction with other organizations concerned with elementary education, particularly the Association for Childhood Education International (ACEI) and the Association for Supervision and Curriculum Development (ASCD). The officers and members of CESI felt that its objectives could best be realized through affiliation with an organization with an executive secretary and other staff members to carry on this work, and, so, in July 1964, CESI voted to affiliate with NSTA as a section, thus combining the offerings of both associations. Among its activities, the section sponsors a luncheon program at the annual NSTA meeting. These sessions attract large numbers of teachers, administrators, and others interested in science at the elementary level.

THE FUTURE

NSTA looks to the future from a well-established interest in science teaching in the elementary school. Even if NSTA continues only as it is now operating, its contributions to the field of elementary school science would be of great importance. But science in the elementary school will not continue as it is now. Hopefully, new methods, new materials, more

research, and certainly new science subject matter will appear, both from inside and outside NSTA. The Association will act to disseminate them. And hopefully NSTA, composed as it is of the most creative minds in the field, will take the lead in sponsoring promising practices, and publish and in other ways make known these practices.

Who can guess the directions elementary school science learning will take in the next ten years? Consider, for example:

1. *The use of special science teachers in various capacities.*
Is this desirable? How can these special teachers be used to best advantage? What should be their preparation?
2. *Changes in the nature of the self-contained classrooms.*
What changes will take place? What will be the role of science in a changed organization? What problems will be involved?
3. *The integrated package deals that supply books, apparatus, visual aids, and other learning materials.*
How will the publication of such materials change the present methods of instruction? How can their effectiveness be evaluated?
4. *The plans for individualized instruction.*
What changes are necessary before individualized instruction can really take place? How important is individualized instruction? How can it best be accomplished?
5. *The establishment of laboratories or more individualized laboratory experiences.*
What kinds of laboratory experiences are important in the elementary school? How can these laboratories be set up and used most effectively? Are they really important?
6. *Increased use of TV and other media of communication.*
What new skills will teachers need in order to participate in and make use of communication media?
7. *The advent of ungraded primary schools.*
How will an ungraded plan affect science instruction? What preparations are essential for teachers in such situations?
8. *The establishment of outdoor laboratories for both urban and suburban student populations.*
Are such laboratories important? What effect will they have on the inner-city dweller?

All of these problems and others will receive attention in the years to come. The Association will assume leadership in assisting its members in evaluating new practices through reports at conferences and meetings. With the growth in number and quality of regional meetings, the work of the Association will come within reach of more and more teachers and other educators.

Bibliography

1. Blough, Glenn O., Ed. *It's Time For Better Elementary School Science* National Science Teachers Association, Washington, D.C. 1958.
2. Blough, Glenn O. *You & Your Child & Science* Department of Elementary-School Principals and the National Science Teachers Association, Washington, D.C. 1963.
3. Hopman, Anne B., Compiler. *Helping Children Learn Science* National Science Teachers Association, Washington, D.C. 1966.
4. "How-to-Do-it" Series. *How to Utilize the Services of a Science Consultant*, 1965; *How to Care for Living Things in the Classroom*, 1965; *How to Teach Science Through Field Studies*, 1965; *How to Record and Use Data in Elementary School Science*, 1965; *How to Individualize Science Instruction in the Elementary School*, 1965; *How to Evaluate Science Learning in the Elementary School*, 1968; *How to Use Photography as a Science Teaching Aid*, 1968. National Science Teachers Association, Washington, D.C.
5. *Investigating Science With Children*. Vol. 1, *Living Things*. Vol. 2, *The Earth*; Vol. 3, *Atoms and Molecules*; Vol. 4, *Motion*. Vol. 5, *Energy in Waves*. Vol. 6, *Space*. NSTA. Published by Teachers Publishing Corporation, Darien, Connecticut.
6. NSTA Curriculum Committee and the Conference on Science Concepts. *Theory Into Action in Science Curriculum Development*. National Science Teachers Association, Washington, D.C. 1964.

AN ANALYSIS OF RESEARCH ON ELEMENTARY TEACHER EDUCATION RELATED TO THE TEACHING OF SCIENCE*

Patricia E. Blosser and Robert W. Howe

The Educational Resources Information Center (ERIC) comprises a network of decentralized clearing houses in various locations throughout

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the United States. The ERIC clearinghouse for science education, located at Ohio State University, is designed to help teachers keep informed of new instructional techniques and materials. The purpose of this article is to report recent research related to the preparation of elementary school teachers to teach science. The following six categories, together with an extensive bibliography, are included: (1) Certification and Requirements for Elementary Teachers, (2) Status of Elementary School Science Teaching, (3) Preservice Preparation in Science for Elementary Teachers, (4) Teacher Competence Research, (5) Teacher Behaviors and Characteristics, and (6) Use of New Media and Techniques in Teacher Education.

The purpose of this article is to report to the profession an analysis of recent research related to the preparation of elementary school teachers to teach science. When a comparison is made with the number of studies of the education in science of elementary teachers with those studies dealing with the preparation of secondary school science teachers, it would appear that science educators have tended to concentrate more of their research efforts on the preparation of teachers for the secondary schools rather than attempting to identify and define problems involved in preparing elementary teachers to do a competent job of teaching science. This situation persists despite the continuing criticisms that many elementary teachers do an inadequate job of teaching science, and also that many are reluctant to teach science. If this situation is to be changed, attention should be given to such problems as finding methods for improving the science competencies of teachers, determining the optimal content background and types of experiences in science for elementary teachers, building more positive attitudes toward science on the part of elementary teachers, as well as continuing the investigations into the area of science content and experiences that should be part of the elementary school curriculum.

CERTIFICATION AND REQUIREMENTS FOR ELEMENTARY TEACHERS

The problem of providing an adequate preservice preparation program in science for elementary teachers has been one of continuing concern to science educators. The recommendation that elementary teachers have at least 20 hours in science was made in the 46th Yearbook of the National Society for the Study of Education, *Science Education in American Schools*, published in 1947. In 1963, the National Association of State Directors of Teacher Education and Certification (NASDTEC) and the American Association for the Advancement of Science (1)[†] published a

[†] See References.

set of guide-lines for science and mathematics in the preparation program of elementary school teachers. This joint committee recommended that every elementary teacher be educated in the fundamental concepts of the biological sciences, the physical sciences, the earth sciences, and mathematics. The development, by colleges, of interdisciplinary courses to illustrate these fundamental concepts was also recommended.

If these recommendations have been acted upon, this action is not yet apparent in state certification requirements as reported by Woellner and Wood (49). There is wide variation among the states in so far as the amount of science which an elementary teacher must have for certification. According to their publication, some states do not specify the amount of credit hours in science needed for certification. Requirements which are specified range from 6 to 15 semester hours, on the average. (California requires a major or graduate work in a single subject, amounting to 24-28 semester hours.) In some states, the amount of science required for certification varies with that required as a part of the general education component of the teacher's under-graduate program. There is very little uniformity to be found. The number of hours required for certification serves to set the minimum standard for preparation, not the optimum.

STATUS OF ELEMENTARY SCHOOL SCIENCE TEACHING

The publication and dissemination of these recommendations and guidelines appear to have had little effect on science teaching as evidenced by research studies in which the status of elementary science teaching has been investigated: Blackwood (5), Smith and Cooper (38), Piltz (31), Moorehead (29), Verrill (44).

Blackwood (5) conducted a survey, under the auspices of the U.S. Office of Education, of science teaching in the elementary schools as it was reflected in teaching practices. As a result of the information gained from the questionnaire sent to elementary schools during 1961-62, Blackwood found that a great variety of purposes, methods, and resources for teaching science existed. He also found that science in the elementary schools is not a subject required by law in most states.

However, science was taught in most of the elementary schools responding to Blackwood's survey. The most common pattern in the early grades was that of science integrated with other subjects. The frequency with which science was taught as a separate subject increased by grade in all school enrollment groups up through grade 5. This tendency toward separation increased in grades 7 and 8. Science taught as (A) a separate subject and (B) as a separate and incidental subject were the most common patterns in the upper grades.

Historically, science in the elementary schools has been taught by the classroom teacher. This was still the situation in the majority of the

schools responding to the questionnaire. The frequency of this pattern decreased with increasing grade level. In a large percentage of schools with enrollments of 400 to 800 students, special teachers teach science to seventh- and eighth-grade students. Some schools, especially those with larger enrollments, had special science teachers from fourth through eighth grades. Regardless of whether a specialist or the classroom teacher taught science, some type of consultant help was available in most schools. A variety of personnel served as consultants, ranging from general elementary supervisors to high school science teachers.

Schools were asked to rank 13 items considered as barriers to effective science teaching. "Lack of adequate consultant service" was ranked first. Blackwood found that science was taught by a classroom teacher without the help of an elementary *science* specialist in over 80 per cent of the schools in grades 1 through 5 and in over 70 per cent of the schools in grades 6 through 8.

"Lack of supplies and equipment," "inadequate room facilities," and "insufficient funds for purchasing needed supplies, equipment, and appropriate science reading materials" were ranked second, third, and fourth in importance. "Teachers do not have sufficient science knowledge" was ranked fifth as a barrier to effective science teaching.

Blackwood concluded that if the inadequacies, revealed through this survey, are to be corrected and the present programs of elementary science are to be improved, reassessment is necessary. Attention should be given to such factors as (A) class size, (B) number of minutes per week that science is taught, (C) developing a systematically planned curriculum in science, (D) the acquisition of adequate supplies and equipment, including library books and other supplementary books and materials, and (E) provision for consultant services, among others.

Smith and Cooper (38) conducted an investigation to determine the frequency of use of eight science teaching techniques by elementary teachers. They attempted to determine the significance of the relationship between the frequency of use of each technique and certain professional and personal characteristics of teachers. They found that teachers with the most formal study in science, in addition to the undergraduate degree, used all the techniques, except reading and discussion of the textbook, with significantly greater frequency than teachers with little or no additional formal study in science. Teachers with the most college training generally used techniques other than reading and discussion of the textbook with greater frequency than those with lesser amounts of college training. However, there was little difference in the frequency with which the two groups of teachers used pupil recording and reporting observations. The researchers concluded that more variety in techniques for teaching science may be expected with better preparation programs and more knowledgeable teachers in the field of science.

Piltz (31) conducted a study to determine what factors, in the opinion

of classroom teachers, handicap the teaching of science in the elementary school. He also wished to determine what relationship, if any, existed between the aspirations of teachers and the difficulties they thought they faced. He found the teachers surveyed to be in general agreement concerning the factors limiting science teaching in the elementary school. The difficulties were of two types: (A) those which could be remedied if the teachers were to attain a better understanding of science and how to teach it, and (B) other difficulties over which the teachers had little or no control. Piltz found conflict concerning content emphasis. He speculated that this conflict arose from the variety of factors that determine the focus of what is taught: the teacher's individual interest and competency, pressure from administrators, pupil achievement, environmental conditions, and the teacher's perception of what is important in the curriculum and in the lives of boys and girls.

Piltz found that a majority of teachers participating in his study considered inadequate physical facilities to be the greatest of all obstacles to effective science teaching. Another obstacle was that of lack of proper materials, equipment, and resources. He also found that some teachers lacked confidence in teaching science and that the majority were weak in the methodology of science teaching. The principals surveyed expressed the opinion that lack of training, of teacher interest, and of time and materials limited science teaching. Few, however, appeared to be doing anything to improve the situation.

PRESERVICE PREPARATION IN SCIENCE FOR ELEMENTARY TEACHERS

Apparently elementary teachers are frequently handicapped in teaching science effectively by conditions existing in many public schools. They may also be handicapped by the preservice preparation they receive. A number of studies related directly or primarily to the problem of preservice preparation in science for grade teachers are: Gant (19), Banks (3), Moorehead (29), Hardin (22), Eaton (15), Service (35), Kisner (24), Chamberlain (10), Esget (17), Bryant (7), Weaver (46), Lerner (26), Gaides (18), Gega (20), Michals (28), Eccles (16), Victor (45), Verrill (44), Cheney (11), Hines (23), Soy (39), Oshima (32).

Banks (3) conducted a study to determine what curriculum arrangements and classroom practices were employed at various teacher education institutions to meet the needs of elementary science teachers. He inferred that science educators may be instilling an "isolationist posture" in preservice elementary teachers by not preparing them to utilize the services of science supervisors and consultants, and also by not emphasizing the possibilities inherent in such cooperative ventures as team teaching. Banks found inadequacies in the present organization of the teacher education program. The fact that science in the elementary school

should be an integral part of the curriculum is not stressed. The pre-service program for elementary teachers, according to Banks' data, also appeared to isolate practical experience, the study of educational psychology, and child growth from science teaching methodology. Another apparent weakness of many science education courses for elementary teachers was that preservice teachers were not involved in a sufficient variety of meaningful situations. Many courses did not appear to be designed to develop, in the preservice teacher, any depth of understanding of why science should be included in the elementary curriculum. Banks theorized that this aspect might have been neglected because the science educators were preoccupied with attempting to convince the preservice teachers that science is not so abstract and incomprehensible as they might have thought.

Gant (19), in a study made from 1957 to 1959, attempted to determine the experiences that elementary student teachers had in science programs in off-campus centers in New York. He concluded that too few elementary student teachers appeared to have problem-solving experiences in science teaching in off-campus cooperating schools, that there was insufficient use of community resources in the science program, that few science consultants were available to help elementary teachers, and that there was a definite lack of experience with such evaluation techniques as achievement and standardized test results, individual interviews with students, and pupil self-evaluation.

Gant suggested that a thorough appraisal of several possible approaches to science instruction be an integral part of the methods and materials course in elementary school science. Responses from the student teachers involved in this study seemed to indicate that the teaching experience would have been more satisfactory if they had had more instructional materials, more guidance in science teaching experiences, and more opportunity for participation in classroom science activities.

Verrill (44), as a part of a study designed to survey the preparation of general elementary teachers to teach science from 1870 to 1961, studied the teacher preparation programs in colleges and universities in a six-state area. He found that few schools had science subject-matter courses especially designed for elementary teachers. Only 19 of the 133 schools surveyed offered survey courses. The number of preservice elementary teachers who obtained their science subject-matter background as a part of the general education requirement was more than double that of any other one particular arrangement.

Chamberlain (10) also investigated the preservice education of elementary school science teachers. As a part of his research, he obtained information from in-service elementary teachers. When these individuals evaluated their college science courses, they found the basic courses in all sciences to be of value as well as courses in science education. They felt that, in pre-service programs, there was a lack of qualified faculty to

handle courses in elementary school science. Their replies seem to support the assumption that if teachers are adequately prepared in science, their problems related to actual teaching are fewer. Many respondents felt that additional training in science would be desirable, but more teachers were concerned with physical problems in the schools, such as lack of space and equipment, which they considered handicaps to effective teaching.

Hardin (22) surveyed the science preparation of preservice elementary teachers at The University of Miami. After analyzing the results of the students' scores on a test designed to reveal competency in science, Hardin concluded that preservice teachers are inadequately prepared. Women students showed greater inadequacy than men students; prospective primary teachers indicated more inadequacy than prospective intermediate teachers. The degree of inadequacy of preparation was revealed to be substantially the same for all five major areas of science. Hardin also concluded that laboratory experiences in addition to the completion of a course in science content and methods were significantly related to competency in science, as evaluated by the instrument used in the investigation.

Service (35) investigated the preservice education in science of elementary teachers at selected California teacher education institutions. He attempted to develop a proposed program of science preparation for elementary teachers. Service suggested that the science preparation program for preservice elementary school teachers should consist of (A) broad, survey-type courses in the biological, physical, and earth-space sciences with emphasis on concept formation, scientific principles, demonstrations and opportunities for practice in science inquiry and (B) courses affording opportunities for study in depth in specific areas, designed for the elementary school teacher.

Gega (20) asked 104 elementary teacher education students to list the things they liked most and disliked most about science courses in an attempt to determine if such information could be useful in improving preservice preparation for elementary teachers. He found that students objected to attempts to cover too much material, emphasis on memorization of unrelated details, tests on trivial objectives, and little or no application of material studied to every-day life, among other things. Gega concluded that, if the comments from the students were acted upon, the preservice courses would have objectives based on student performance, subject matter organized about relatively few generalizations, an emphasis on important social and practical applications of material studied, and would involve laboratory experiences. He suggested that these courses be taught by instructors with interests and training suitable for teaching an interdisciplinary course in science for non-majors.

Gega noted that a professional education course in elementary science should introduce students to basic knowledge and methods in several areas of science. Such a course should also include information on how science

is organized in elementary schools, the strategies and tactics of science teaching, methods of evaluation, and methods to plan lessons that incorporate all these considerations.

Lerner (26) conducted a study to determine the status, trends, objectives, content, instructional procedures, and problems related to the methods course in elementary school science in selected four-year institutions of higher education. She found that 78 percent of the 291 institutions she surveyed provided training in methods for elementary school science, although some institutions apparently had a multiple methods course for elementary teachers rather than one devoted solely to the teaching of science in the elementary school. The instructors surveyed reported three major problems: the poor science background of their students, lack of favorable facilities for laboratory work, and class enrollments which they considered too large for effective teaching conditions. One of the primary problems in the multiple methods course was the lack of time to teach methods for more than one content area in a single course.

Victor (45), operating on the premise that the assumption that elementary teachers were reluctant to teach science was a valid one, surveyed 106 teachers in one school system to determine why they were reluctant to teach science. He found that a lack of familiarity with science content and materials, due to an inadequate science background, was a major factor. Eleven of the teachers responding to Victor's questionnaire had had no science beyond general science in high school. However, 75 per cent of those surveyed had two full years of college science. Victor found that those teachers with a background in college science spent more time teaching science and used demonstrations and experiments more often than did those teachers having fewer courses in science.

Hines (23) also conducted a study related to the assumed reluctance of elementary teachers to teach science. She attempted to determine possible relationships existing between this reluctance and nine different factors. She found that teachers were providing more time for science teaching, demonstration, and experimentation than one would expect from a review of the research. She also found that an inadequate science background is a definite factor influencing science teaching at the elementary school level. Hines concluded that the number of years of teaching experience, the grade level being taught, and the experience of having had a science methods course appeared to have little effect on the teaching performance of the population involved in her study. The differences that occurred among groups appeared to be due primarily to the types of classroom teaching situations.

Eaton (15) surveyed elementary education students enrolled at the University of Texas to determine why few of them elected science as an area of subject-matter concentration. He found that the students received little guidance from the faculty although they received considerable

discouragement from their peers in selecting an area of science. After observing teacher behavior and surveying prospective teacher attitudes, he concluded that students lacked insight into the application of a concentration in subject matter to the teaching act. Apparently they need help in perceiving the relationship between content and instruction.

Soy (39) also investigated the attitudes of prospective elementary teachers toward science as a field of specialty. She found that interest was a most important reason for choosing a subject field. She discovered that science received the fewest votes as a high school subject in which students had felt most successful. Science ranked fifth of the seven subject areas in which students felt prepared to teach, although it was ranked first among the subjects which the student teachers felt elementary students would like to study. Soy concluded that something must be done to give preservice elementary teachers more satisfying experiences in science.

Oshima (32) compared two methods of teaching a science methods course for prospective elementary teachers. He found that the two different methods used in the study, lecture-demonstration and individual investigation, produced no significant changes in attitudes toward science. However, the experimental group which had been conducting individual investigations did make significant gains in their confidence toward teaching science.

Cheney (11), in a study designed to increase the commitment of preservice elementary teachers to teaching science, found that the students involved had little inclination to become specialists in elementary science either before or after the teaching-learning experience. He found that the tendency of the students to deplore their weaknesses in science knowledge was not matched by efforts to remove deficiencies through self-study or extended laboratory investigations. The students did appear, however, to gain confidence in their ability to teach science.

The breadth and depth of science content background acquired by an elementary teacher appears dependent on a number of factors. One of these relates to the graduation requirements of the particular institution in which the preservice teacher is enrolled. The amount of science required in the general education component of a preservice teacher's preparation is limited. Often no provision is made for attaining a balance in the various fields of science. Another determining factor is that of the teacher's interest in and attitude toward science. Attitude development is, apparently, a long term process. Attitudes, once established, are not likely to be changed as a result of the experiences which the preservice teachers have in one course of only one quarter or one semester's duration. The preservice teachers frequently take only one methods course which is a general one related to the various disciplines involved in the elementary curriculum. Again, time is too limited for provision of adequate experiences in science teaching methodology. A third factor is that of the guidance, or lack of it, which the individual receives in planning his

program. The majority of the researchers whose studies are cited in this part of the paper appear to conclude that the present preparation programs are inadequate for teaching science, in an effective manner, in the elementary school.

TEACHER COMPETENCE RESEARCH

Perhaps the teaching of science in the elementary school could be improved if science educators were to concentrate upon developing a set of competencies which elementary teachers should possess relative to the teaching of science rather than assuming that the completion of a certain number of credit hours of course work will produce teaching effectiveness in a classroom situation. A current interest in teacher education appears to be concerned with this approach to preservice education. A number of investigations were concentrated upon the determination and development of competencies in science that elementary school teachers should possess: Uselton (43), Uselton, Bledsoe, and Koelsche (42), Sharefkin (36, 37), Reed (33), Michals (28), Butts (8), Mattheis (27), Moyer (30a), Cunningham (13), Weigand (47), Senter (34), DiLorenzo and Halliwell (14), Bryant (7).

Michals (28) conducted an investigation relevant to the topic of teacher competence. He attempted to determine the desired objectives for the preparation of teachers for teaching elementary science, the kinds of experiences that would produce competent elementary teachers, and the kind of science education programs needed. He selected as desired competencies three of the six roles of the teacher formulated in a study by the California Teachers Association: the director of learning, the mediator of the culture, and a member of the profession. Course activities were considered for selection in terms of three criteria: (A) is the experience practical preparation for elementary science teaching? (B) is the experience related to the operational definition of objectives? and (C) can the experience be evaluated? Three courses were set up at two different institutions and evaluated on the basis of a rating scale and the results of an Elementary Science Education Test. Michals found that there was a higher level of student achievement in the general discussion and group activities class than in the lecture-demonstration class. The schedules of the two institutions were not identical. This resulted in one class, at one institution, meeting 40 times as compared with the 24 times that each of the other two classes met. Michals found, upon analyzing the data, that approximately the same per cent of students in the two experimental courses, at the two different institutions, achieved the objectives when an equal amount of time was available for each topic and the same method of presentation was used. However, when additional time was available, a higher per cent of students achieved the objectives. It would appear that the amount of time needed to achieve the desired

objectives needs to be investigated. The level of achievement of these objectives also needs to be assessed.

Sharefkin (36) investigated the science knowledge and competencies of students enrolled in a liberal arts college. She attempted to identify the relationship between the college science training of student teachers and the student teachers' appraisal of their need for, as well as the extent to which they believe they possess, science abilities. She considered such abilities as those related to (A) identifying and defining problems, (B) suggesting or screening hypotheses, (C) selecting validating procedures, including the design of experiments, (D) interpreting data and drawing conclusions, (E) evaluating critically claims and statements of others, and (F) reasoning quantitatively and symbolically. The majority of the students participating in the study were aware of their need for science abilities. They appeared to feel that they were strongest in the areas of identifying and defining problems and in interpreting data and drawing conclusions. Only 34.8 per cent of those investigated thought they needed to be able to reason quantitatively. Sharefkin suggested that criteria are needed to help student teachers clarify their own conceptions of, as well as identification of, children's behaviors which exhibit the science abilities emphasized in the study. She inferred that the student teachers' major difficulties were related to evaluating their science teaching and implementing science objectives. She concluded that elementary school student teachers need to develop awareness of their limitations so that they can critically examine their approach to teaching science and can function constructively in professional growth and teaching competence.

Problem-solving is another skill which it is assumed that teachers should possess. Butts (8) conducted a study with 21 college seniors in an elementary science teaching methods course in order to measure their problem solving behavior. He wanted to determine the possible relationship between the knowledge of scientific facts and principles and the problem-solving behavior of the students. He found that problem-solving behavior was not characterized by patterned thought in this study. He hypothesized that teachers need to be trained to (A) focus on their ability to use knowledge rather than on the accumulation of knowledge, (B) search for basic principles rather than to memorize facts, (C) critically analyze data rather than to accept scientific facts without qualification, and (D) generalize from basic principles and scientific applications.

Mattheis (27) investigated the effect on the competence of preservice teachers for teaching science produced by two different types of laboratory experiences. He was interested in competence as it was reflected in subject-matter achievement and interest in science. He tested the assumption that laboratory experiences in science are necessary if the preservice education of elementary school teachers is to be successfully accomplished. The experimental group used a science-project approach to laboratory work while the control group was taught by the conventional

replication-verification method. Mattheis found that, with respect to knowledge of science, the project approach to laboratory experiences was more efficient for students who exhibited strong interest and a proficient knowledge of science. However, students who were not interested in and who did not know very much about science learned more science when they were in the control group. Students were divided in their preferences for the two approaches to laboratory work. Some suggested that the good points of both types of laboratory work be utilized to develop a suitable laboratory course for preservice elementary teachers.

Two studies, Moyer (30a) and Cunningham (13), were concerned with development of competence in question asking. Moyer observed and tape recorded 14 science lessons, in five different elementary schools, involving 12 teachers. He compiled a total of 2,500 questions. Moyer found that over 50 per cent of the questions were initiated with WHAT, HOW, WHY, WHO, WHERE, WHICH, and WHEN. He did not, however, find any evidence of a question that required students to evaluate. Moyer found that teachers with undergraduate majors in a field other than education tended to ask more questions requiring the children to explain than did those who had majored in education. He inferred that teachers are not prepared to develop and use questions effectively, and that teachers tend to frame questions in such a way that their pupils are not truly stimulated to think about and develop adequate concepts.

Although many teacher educators emphasize the use of sound questions to encourage children to think and caution their students to avoid telling children everything, this advice does not appear to be followed. However, Moyer found that the teachers he interviewed reported they received almost no instruction or suggestion relative to the methods of developing and utilizing questions as a part of their preparation for teaching.

Cunningham (13) conducted a study to determine the effects of a method of instruction designed to improve the question-phrasing practices of prospective elementary teachers. Forty elementary education majors participated in the study. He found that the ability of the prospective elementary teachers to construct a greater proportion of effectively phrased questions could be improved by the techniques which he used. The students who participated in the study also learned to construct a greater proportion of divergent questions for their science teaching.

Weigand (47) investigated another facet of the questioning process. He wished to determine if the ability of prospective elementary school teachers to ascertain the relevancy or irrelevancy of children's questions in elementary school science could be improved. He also investigated the effects, if any, of the preservice teacher's content background and academic grade-point average on this ability. He found that prospective teachers could determine the degree of relevancy of children's science questions and that this ability could be improved. Academic ability did not prove to be a factor affecting the ability to analyze questions. On the basis of the data he collected, Weigand inferred that factors other than

subject-matter content were important in analyzing the relevancy or irrelevancy of science questions of children.

Two research studies were concerned with the use of specialists to teach science in the elementary schools, Senter (34) and DiLorenzo and Halliwell (14). Senter investigated the level of science achievement of sixth-grade students as it was related to teacher factors such as age, teaching experience, concentration in science courses, and styles of teaching. Analysis of the data relative to certain science knowledge, understanding, and concepts held by the students did not reveal any significant differences in the test results between students from self-contained classrooms and those in departmentalized classroom situations.

DiLorenzo and Halliwell (14) investigated the science achievement of 258 sixth-grade children to compare the scores of those taught by regular classroom teachers with the scores of children taught by special science teachers. They found no true difference in achievement of the two groups for either boys or girls. They did, however, hypothesize that different results might have been obtained if their investigation had lasted longer than seven months. They also questioned the use of available standardized tests in science as being valid appraisals of the objectives of the newer science programs.

It might be assumed that the competencies needed by teachers in the primary grades would be different from those needed by upper elementary school teachers. Bryant (7) considered this possibility as a part of his investigation designed to determine the amount of attention given, in required science courses, to the science understandings considered important for children. He found no substantial evidence of any difference in training in the institutions studied. Only 3.7 per cent of these institutions reported any differentiation in requirements. In general, the science training programs for elementary school teachers were the same for all grade levels. There was no evidence to indicate that those who plan the programs think that it should be otherwise. Bryant found discrepancies between what children are expected to learn in science and the science education of preservice teachers to prepare them to facilitate this learning. This would suggest that elementary science curricula of institutions preparing teachers should be critically examined.

The question of teacher competence requires further investigation. Definite objectives need to be defined and assessed. The degree of competence a preservice teacher can be expected to achieve as a result of courses and experiences gained during a period of undergraduate education needs to be ascertained. Research should be done to determine if primary teachers need a set of competencies different from those needed by upper-grade teachers. If a set of desired competencies can be formulated, further research will need to be done to determine the sequence of courses and experiences to be included in the preparation program in order to achieve these competencies.

TEACHER BEHAVIORS, CHARACTERISTICS

A number of researchers were interested in investigating the variables of teacher behavior and characteristics as these related to effective science teaching in the elementary school: Reed (33), Wishart (48), Beringer (6), Taylor (40), Hardin (21), Uhlhorn (41), Coffey (12).

Wishart (48) conducted research to determine the relationship of selected teacher factors to the character and scope of the science teaching program in self-contained elementary school classrooms as evidenced in 48 elementary classrooms. He found a number of significant differences among teachers relative to their backgrounds and understandings of science. Considerable differences were revealed relative to science teaching practices. Teacher understanding of science and understanding of child development appeared to be significantly related to each other. Understanding in those areas appeared to be greatest for teachers with the least authoritarian tendencies.

Reed (33) conducted a study of the influence of teacher variables on student learning. He chose to investigate teacher warmth, teacher demand, and the teacher's utilization of intrinsic motivation. His learning criterion was the pupils' interest in science as measured by the Reed Science Interest Inventory. There appeared to be a positive correlation between the teacher's use of intrinsic motivation and pupil interest in science. There was also a positive and moderately strong correlation between teacher warmth and pupil science interest.

Reed found a strong tendency for teacher demand or the degree of expectations concerning the students' maintenance of high standards of performance on school tasks and the utilization of intrinsic motivation to exist in the same teacher. He found the variables of teacher demand and warmth to be independent. Reed inferred, from an analysis of his data, that moderate demand does not necessarily sacrifice such goals as science interest. He postulated that preservice teachers could learn to become skillful in the use of intrinsic motivation as a part of their preparation programs in science education. Warmth, however, is a characteristic less amenable to development through teacher education experiences.

Beringer (6) was interested in determining whether the recency of a teacher's preservice education was related to the teacher's ability to understand scientific facts. She was also interested in discovering if the grade level at which the teacher worked and the amount of physical and biological science background the teacher possessed were relevant to this ability. After analyzing the 290 returns from the *Scientific Fact Test for Elementary Teachers*, Beringer concluded that teachers who were trained 1 to 4 years ago had a better understanding of scientific fact than teachers who have been out of college for 25 years. She found that teachers in the upper-elementary grades have a better understanding of scientific fact than teachers in the lower-elementary grades. Teachers appeared to have a

better understanding of the biological sciences than of the physical sciences. However, in every category there were great variations in the percentages of correct answers. Apparently there are gaps in teachers' understandings of scientific fact in all areas of science.

Taylor (40) analyzed the teachers' attitudes toward instructional materials in a programed learning situation in science and the relationship of these attitudes to pupil achievement. He worked with 16 fourth-grade teachers and 89 randomly selected pupils for a four and a half month period. He concluded that while teacher attitudes toward programed science materials do not contribute significantly to measured pupil attitudes toward these materials, there was evidence that teacher attitudes influenced potential pupil achievement. Teacher attitudes appeared to contribute 18 per cent of the variance in pupil final achievement. The teachers' attitudes were significantly correlated with their responses to the instrument *How I Teach: Analysis of Teaching Practices*.

Hardin (21), in a study designed to investigate dimensions of pupils' science interest and of their involvement in classroom science experiences in selected fifth- and sixth-grade classes, found that pupils could distinguish various aspects of their classroom experiences. The pupils appeared to be keenly aware of the teacher-pupil relationships. These relationships were highly significant to pupils, with warm teacher-pupil relationships being an important component of an effective teaching-learning situation.

Uhlhorn, Boener, and Shimer (41) found the ability to establish rapport with children to be an important teacher characteristic. They conducted an investigation in conjunction with a pre-student teaching experience in science for elementary education students at Indiana State University. Two other characteristics that appeared to be important in determining the success of the lesson were the ability to use teaching aids and the depth and breadth of knowledge of the subject included in the lesson. The researchers felt that further investigation needs to be done before it can be concluded that these characteristics are vital to successful science teaching.

Coffey (12) investigated the verbal behavior of teachers of the lower-elementary grades. He found significant differences between the pre-and post-tests of the experimental group, based on an analysis of interaction analysis data, relevant to their understanding of science and their attitudes toward science. He inferred that the procedures used in this study facilitated the teachers' perceptions of learner needs and strategies of teaching which enhance learner needs.

USE OF NEW MEDIA AND TECHNIQUES IN TEACHER EDUCATION

Two investigations were reviewed which involved the use of some of the

newer procedures in the education of elementary school teachers. Ashlock (2) and Kriebs (25). Ashlock (2) used micro-teaching in an off-campus methods course for elementary school teachers. Micro-teaching involves teaching a lesson of 5 to 20 minutes length to a class of 4 to 8 students. The students taught a 5-minute lesson, which included a demonstration, to four of their peers who served as pupils for the microclass. Ashlock and his students found that if the lesson objectives were not stated in terms of the desired pupil behavior, the teacher had difficulty in achieving instructional closure.

Kriebs (25) conducted a study to compare the effectiveness of two types of videotaped instruction for preparing elementary school teachers to teach science. She was interested in determining if preservice teachers who observed videotapes of elementary school children using scientific methods performed significantly better as science teachers than did those preservice teachers who observed videotapes of a traditional lecture-demonstration class not involving children. The students involved in the study were videotaped in a teaching situation before the experimental treatment began and were again videotaped at the end of the experimental treatment. Kriebs based her comparison on the results of a paper and pencil test as well as on direct observation of teaching performance. She found there was no significant change in the preservice teachers' classroom performances as a result of the experimental treatment. However, those students who had viewed the videotapes involving children tended to receive higher ratings on their classroom performance than those who had viewed the control videotapes. The preservice teachers who had viewed the control videotapes gained significantly more science knowledge over the same content than did those who had viewed the experimental videotapes involving children. It would appear that there is no one easy method to provide both science content and teaching methodology.

SUMMARY AND RECOMMENDATIONS

Research studies concerned with the preparation of teachers to teach science to elementary school children have been reviewed, as have guidelines for preparation programs. Studies which focused on the status of elementary school science teaching were also included in the review. Research related to inservice education programs in science for elementary school teachers was not included in this article.

It might be inferred, from an analysis of these research reports, that elementary school science teaching is handicapped by deficiencies in both course content and teaching methodology in so far as teachers' backgrounds are concerned as well as by inadequate teaching conditions in the schools. Individuals desiring to teach at the elementary school level cannot be prepared as specialists in all of the subject-matter areas which

they are called upon to teach in a self-contained classroom, at least within the present four-year preparation period. If the length of the preservice program is not to be extended, preparation in depth and breadth within a particular subject-matter area is limited. Students preparing to teach elementary school frequently take one general course in teaching methodology. Again, due to time limitations, they do not receive training and experiences in sufficient depth in all of the subject-matter areas. Frequently, students do not have the opportunity during their student teaching experience to teach all of the subjects included at that particular grade level. Elementary school teachers, because they lack familiarity with science content and materials, express reluctance to teach science. Research needs to be done to determine how the preservice program for elementary school teachers can be structured to provide as wide a range of experiences and instructional content in science as possible.

Current certification patterns appear to be based on courses completed rather than upon classroom performance. Are the concepts of *legally qualified* and *competent* teachers equivalent ones? More research should be conducted relevant to the problems of teacher competence. A publication entitled *Six Areas of Teacher Competence* (9) details six roles of the teacher: director of learning, counselor and guidance worker, mediator of the culture, link with the community, member of the school staff, and member of the profession. Are all of these of equal importance in the preparation of elementary teachers? The authors of this publication expect beginning teachers to possess minimum competence in each role. Is it possible that not all beginning teachers are aware of the fact that they are expected to function in these roles? Are preparation programs perpetuating the stereotype role of the teacher as a purveyor of information? Does current emphasis upon learning by discovery hold implications for the modification of any of these roles? Does an individual who thinks of himself as a *director* of instruction function in a manner calculated to develop students who are independent learners? More research needs to be done in science education at the elementary school level to show the relationship between preparatory programs and product outcomes.

Teaching involves interaction between the teacher and students. Research studies based on the investigation of teacher-pupil interaction in science need to be extended downward into the elementary school. Those studies which have been done have been limited to observations of situations involving the teacher and the majority of the class. Elementary teachers work with individual students and with small groups to an even greater extent than do secondary school teachers. Research should be done to determine how science activities taking place during such sessions differ, if they do, from those times in which the teacher is involved in working with the entire group.

Few research studies have been done to lead to the development of any

theory of instruction relative to science teaching, at either the elementary or the secondary school level. Would adequate research result in the development of a theory of teaching science that would differ from theories for teaching other subjects? Would it differ for different levels of maturity of the students? Would it differ if science were to be taught to elementary school children by a teacher specializing in science as opposed to the present classroom teacher who has been trained to function as a generalist?

Research needs to be done relevant to the ways in which elementary teachers handle the problem of individualization of science instruction and the ways in which they accommodate for individual differences of their students.

Within the last five to eight years new programs have been appearing in elementary school science. Are preservice teachers being prepared to do an effective job with these new courses and materials? Teachers have to implement programs which they did not help to originate. Both beginning and experienced teachers need to know what to do in terms of both content and instructional strategies, how to implement the strategies involved, and they also need to understand the underlying rationale of the program. Research should be done to determine the degree to which prospective elementary teachers are being prepared to make effective use of the new elementary science projects.

In addition to the development of new programs in elementary school science, elementary education is being affected by such developments as team teaching, the ungraded elementary school, programed instruction, and new materials and media. Are prospective teachers being prepared to function in such a changing environment?

Barnard (4), in discussing Bruner's *The Process of Education*, says that Bruner's ideas imply "... all children should be able to find the cognitive aspect of science an intellectually stimulating experience." This implies that elementary school teachers need to help children learn how to learn and to structure the experiences so that the students can be led to discover concepts on their own. To accomplish this, the teachers should be individuals who have found the study of science to be a personally satisfying experience. Can the preservice program be restructured to accomplish this goal?

Science education is faced with unresolved issues in the different areas described in this paper. Exact knowledge of these issues is essential for continued development of the education of science teachers, at both the elementary and the secondary school levels. Basic questions need to be asked and researchable problems identified. Areas for study should include those concerning the content and experiences to be provided in the preparatory programs, the relationship of the content and experiences to teacher behavior, and the relationship of resulting teacher behavior to the behavior of students in the classroom situation.

References

1. American Association for the Advancement of Science. "Guidelines for Science and Mathematics in the Preparation Program of Elementary School Teachers." Washington, D. C. 1963.
2. Ashlock, Robert B. "Micro-Teaching in an Elementary Science Methods Course." *School Science and Mathematics*, January 1966.
3. Banks, William Henry. "Practices in the Preparation of Elementary Teachers for the Teaching of Science." University Microfilms, Ann Arbor, Michigan. 1965.
4. Barnard, J. Darrell. "What Can Science Contribute to the Liberal Education of All Children?" *The Science Teacher*, November 1965.
5. Blackwood, Paul E. "Science Teaching in the Elementary Schools." U.S. Office of Education, Washington, D. C. 1965.
6. Beringer, Marjorie L. "A Critical Analysis of Teacher Understanding of Scientific Fact." University Microfilms, Ann Arbor, Michigan. 1965.
7. Bryant, Paul P. "Science Understandings Considered Important for Children and the Science Required of Elementary School Teachers." University Microfilms, Ann Arbor, Michigan. 1959.
8. Butts, David P. "The Relationship of Problem-Solving Ability and Science Knowledge." *Science Education*, March 1965.
9. California Teachers Association. "Six Areas of Teacher Competence." Burlingame, California. 1964.
10. Chamberlain, William D. "Development and Status of Teacher Education in the Field of Science for the Elementary School." University Microfilms, Ann Arbor, Michigan. 1955.
11. Cheney, Bruce D. "Commitment of Science Teaching Among Prospective Elementary School Teachers: An Exploratory Study." Unpublished doctoral dissertation. University of Illinois, Urbana, Illinois. 1966.
12. Coffey, Warren C. "Change in Teachers' Verbal Classroom Behavior in Science Education." Unpublished doctoral dissertation. University of California, Berkeley, California. 1967.
13. Cunningham, Roger T. "A Descriptive Study Determining the Effects of a Method of Instruction Designed to Improve the Question-Phrasing Practices of Prospective Elementary Teachers." Unpublished doctoral dissertation. Indiana University, Bloomington, Indiana.
14. DiLorenzo, Louis T. and Joseph W. Halliwell. "A Comparison of the Science Achievement of Sixth-Grade Pupils Instructed by Regular Classroom and Special Science Teachers." *Science Education*, March 1963.
15. Eaton, Edward J. "An Examination of the Development of Science Concentrations for the Prospective Elementary School Teacher at the University of Texas." *Journal of Research in Science Teaching*, September 1966.
16. Eccles, P. J. "A Comparison of the Science Background of Elementary Teachers-in-training at the University of Alberta, Calgary, and the University of Illinois." *Alberta Journal of Educational Research*, March 1962.
17. Esgert, Miles H. "Developing and Using an Objective Instrument to Measure Student Growth in College Elementary School Science Courses." University Microfilms, Ann Arbor, Michigan. 1958.
18. Gaides, Glen E. "A Comparison of Learnings by Elementary Education Majors in Selected Physical Science Courses." University Microfilms, Ann Arbor, Michigan. 1962.

19. Gant, Kenneth A. "A Survey of the Curricular Experiences Available to Elementary Student Teachers in Science Programs in Northern Zone (New York State) Schools During the 1957-59 Period as Evidenced by Reactions of Elementary Teachers, Elementary Supervisors, and Elementary Student Teachers and Compared with 'Best Practices' as Indicated by Selected Jurors." University Microfilms, Ann Arbor, Michigan. 1962.
20. Gega, Peter C. "The Preservice Education of Elementary Teachers in Science and the Teaching of Science." *School Science and Mathematics*, January 1968.
21. Hardin, Elizabeth H. "Dimensions of Pupils' Interest in Science and of Their Involvement in Classroom Science Experiences in Selected Fifth- and Sixth-Grade Classes." University Microfilms, Ann Arbor, Michigan. 1964.
22. Hardin, Henry N. "An Analysis of Selected Aspects of the Science Preparation of Prospective Elementary Teachers at the University of Miami." University Microfilms, Ann Arbor, Michigan. 1965.
23. Hines, Sallylee H. "A Study of Certain Factors Which Affect the Opinions of Elementary School Teachers in the Teaching of Science." Unpublished doctoral dissertation. Oklahoma State University, Stillwater, Oklahoma. 1966.
24. Kisner, Andrew J. "Science Content Preparation of Prospective Elementary School Teachers in Eight Oklahoma Institutions of Higher Education." University Microfilms, Ann Arbor, Michigan. 1963.
25. Kriebs, Jean O. "The Effect of Videotaped Elementary School Science Classroom Demonstrations on Science Teaching Performance of Preservice Teachers." Unpublished doctoral dissertation. Temple University, Philadelphia, Pennsylvania. 1967.
26. Lerner, Marjorie S. "An Investigation of the Status of the Methods Course in Elementary School Science in Selected Teacher-Training Institutions." University Microfilms, Ann Arbor, Michigan. 1964.
27. Mattheis, Floyd E. "A Study of the Effects of Two Different Approaches to Laboratory Experiences in College Science Courses for Prospective Elementary School Teachers." University Microfilms, Ann Arbor, Michigan. 1962.
28. Michals, Bernard E. "The Preparation of Teachers to Teach Elementary School Science." *Science Education*, March 1963.
29. Moorehead, William D. "The Status of Elementary School Science and How It Is Taught." University Microfilms, Ann Arbor, Michigan. 1965.
- 30a. Moyer, John R. "An Exploratory Study of Questioning in the Instructional Process in Elementary Schools." Unpublished doctoral dissertation. Teachers College, Columbia University, New York City. 1965.
- 30b. Obourn, E. S.; Blackwood, P. E. *et al.* "Research in the Teaching of Science, July 1957-1959. U. S. Office of Education, Washington, D.C., 1962.
31. Piltz, Albert. "An Investigation of Teacher-Recognized Difficulties Encountered in the Teaching of Science in the Elementary Schools of Florida." University Microfilms, Ann Arbor, Michigan. 1954.
32. Oshima, Eugene A. "Changes in Attitudes Toward Science and Confidence in Teaching Science of Prospective Elementary Teachers." University Microfilms, Ann Arbor, Michigan. 1966.
33. Reed, Horace B. "Implications for Science Education of a Teacher Competence Research." *Science Education*, December 1962.

34. Senter, Donald S. "An Appraisal of an Elementary School Science Program." Unpublished doctoral dissertation. Wayne State University, Detroit, Michigan, 1966.
35. Service, Randolph G. "A Proposed Program of Science Preparation for Elementary Teachers." University Microfilms, Ann Arbor, Michigan. 1964.
36. Sharefkin, Belle D. "A Possession of Science Abilities and Its Relationship to Student Teacher Training in a Liberal Arts College." *Science Education*, December 1962.
37. Sharefkin, Belle D. "The Relationship Between Elementary School Student Teachers' Science Abilities and Their Self Appraisals." *Science Education*, October 1963.
38. Smith, Doyne M. and Bernice Cooper. "A Study of the Use of Various Techniques in Teaching Science in the Elementary Schools." *School Science and Mathematics*, June 1967.
39. Soy, Flois M. "Attitudes of Prospective Elementary Teachers Toward Science as a Field of Specialty." *School Science and Mathematics*, June 1967.
40. Taylor, Alton L. "Teacher Attitudes, Pupil Behavior, and Content Attributes in Relation to the Use of Programmed Science Materials at the Fourth Grade Level." University Microfilms, Ann Arbor, Michigan. 1965.
41. Uhlhorn, K. W., C. M. Boener, and S. S. Shimer. "An Evaluation of the Science Pre-Student Teaching Experience for Students Enrolled in the Elementary Education Curriculum at Indiana State University." Paper presented at NARST meeting. 1967.
42. Uselton, Horace W. *et al.* "Factors Related to Competence in Science of Prospective Elementary Teachers." *Science Education*, December 1963.
43. Uselton, Horace W. "Factors Related to Competence in Science of Prospective Elementary Teachers." University Microfilms, Ann Arbor, Michigan. 1962.
44. Verrill, John E. "The Preparation of General Elementary Teachers to Teach Science, 1870 to the Present." University Microfilms, Ann Arbor, Michigan. 1961.
45. Victor, Edward. "Why Are Our Elementary School Teachers Reluctant to Teach Science?" *Science Education*, March 1962.
46. Weaver, Allan D. "A Determination of Criteria for Selection of Laboratory Experiences Suitable for an Integrated Course in Physical Science Designed for the Education of Elementary School Teachers." University Microfilms, Ann Arbor, Michigan. 1954.
47. Weigand, James E. "The Relative Merits of Two Methodologies for Teaching the Analysis of Children's Questions in Elementary School Science." University Microfilms, Ann Arbor, Michigan. 1965.
48. Wishart, Allington P. "The Relationship of Selected Teacher Factors to the Character and the Scope of Science Teaching Programs in Self-Contained Elementary School Classrooms." University Microfilms, Ann Arbor, Michigan. 1961.
49. Woellner, Elizabeth H., and M. A. Wood. *Requirements for Certification*, Third Edition. University of Chicago Press, Chicago, Illinois. 1968.

TEACHER EDUCATION AND ELEMENTARY SCHOOL SCIENCE—1980*

Willard J. Jacobson

Willard J. Jacobson describes what the elementary school teacher of tomorrow must be in order to fulfill the demands of elementary science education for the future. He believes that the future teacher should develop an understanding of the scientific view of man and his world, the conceptual structure of science, the processes of science, and the inter-relationship of science, technology, and society. He should also devote a significant portion of his teacher education to the study of man. The future teacher will spend his time planning individual programs of study, considering laboratory investigations, analyzing his teaching experiences, and discussing thought-provoking ideas in education and science.

How can we prepare the elementary school teachers of tomorrow? How can we educate the teachers who will help our children to have rewarding and significant experiences in science? Before we consider some of our approaches to teacher education, let us try to picture the teacher of the future. What will this teacher look like? What should he† be able to do? Let us try to describe what this teacher for tomorrow may be like and some of the ways in which he will operate.

Obviously, our teacher of the future should have a pleasant, warm personality, love for children, and a curiosity about the world in which we live. Perhaps, there is very little that we can do through education to develop these personality traits, but some of them may be acquired in elementary schools through association with fine teachers. In the tomorrow, we shall be more selective as we choose candidates for our teacher preparation programs. Since it will be recognized that teaching is our most important social undertaking, some of our best young people will be attracted to careers in teaching.

* REPRINTED FROM *Journal of Research in Science Teaching*, Vol. 5, Issue 1, 1968, pp. 73-80. Reprinted by permission of the author and the publisher. Dr. Jacobson is Chairman of the Department of Science Education at Teachers College, Columbia University.

† One of the characteristics of our future elementary school teacher population should be that it contains both men and women. It is suggested that each child should have the experience of having a male teacher at least once during the years that he is in the elementary school. In this paper the masculine pronoun represents both male and female teachers.

Our teachers of the future should have a general understanding of the nature of the physical and mental growth of children. They will understand the stages of growth and be able to use this understanding in planning educational programs. Of perhaps greater importance, they will be able to use this understanding to interpret the behavior of children. For these teachers, this interpretation will not take the form of a protracted analysis. Instead, it will be an almost intuitive operational analysis used during the process of teaching. They will know children and use the knowledge to know the child.

Our teacher of the future will have mastered a wide range of approaches to teaching. He will know how to ask questions that lead children into inquiry. And he will listen to the responses of children and build educational experiences in terms of these responses. He will work with children as individuals, in small groups, and as an entire class and know how to help them initiate projects and how to support them when they meet frustration. He will know how to organize laboratory experimentation, but he will also work with groups in cooperative investigations. Field studies, whether they be in the community or in the school system's outdoor laboratory, are a part of his program. His children learn how to use the library and the many learning resources available there. Our future teacher will deliberately use a variety of approaches to teaching during the course of a day. Since he will be sensitive to the moods and attention of the children, the changes in teaching style will seem to be naturally coordinated with the changing moods and interests of the children.

We are developing a wider range of possible approaches to elementary science. Resources, materials, and equipment of many different kinds are available. Our future teacher will keep informed of these new developments, and will know how to use the new materials. Hopefully, his school will make them readily available for his use.

This teacher of the future will also know how to use the many technological devices that are available to teachers. The teacher can bring the outside world into the classroom via television, radio, and conference telephones. The conference telephone brings a variety of experts into the classroom, the communications satellites bring the world onto the screen. Projectors of a variety of kinds are used to illustrate ideas. Technological devices for which suitable programs have finally become available are used by the children as they study and learn. These are all technological devices that can be used to improve instruction. Very sophisticated information retrieval systems to obtain information that is needed will also be available, as the children explore in science. The teacher and his class have the resources of the Library of Congress readily available to them. The children can "be there" as recent events in the history of science are recapitulated via the video tape recorder.

The children in this classroom of the future are widely traveled. None of them began his education in this school; many of them have attended three or four other schools. This is now considered to be an advantage rather than a handicap. Our teacher of the future knows how to use the battery of diagnostic instruments available to him to prescribe the "ideal" education for each child. The variety of experiences that the children have had lead to rich and informative discussions. For example, when a group becomes engaged in the study of fossils, one child recalls his visits to the LaBrea Tar Pits, while another has taken part in the excavation of a dinosaur footprint in the Connecticut River Valley.

Our teacher of the future will have a fine operational understanding of the broad generalizations of science. True, he will not have studied the details of anatomical structures (that drove some of his predecessors away from science when they took the biology course designed for pre-medical students), nor will he work some of the

time-consuming problems at the end of the chapters in the book used in a physics class that once served as a screening device for a graduate department of physics; but, he will know science. He will have a mental picture of man and the world that is generally consistent with that developed in the various sciences. He also will have an understanding of the conceptual structure of science. Perhaps, this teacher will have a particular interest in the relationships between science, technology, and society.

This understanding of science includes an understanding of the methods of inquiry in various sciences. Some of our future teachers, for example, may be especially interested in the methods of collecting, handling, and evaluating of data. As they collect evidence of physical growth or of the developing understanding of scientific concepts and try to relate the data to phases of the instructional program, they will encounter some of the same problems that scientists meet.

As a result of the liberating education that they will have had, many of these teachers will have developed a special interest in one area of science. One of these teachers may be interested in the breeding of a rather rare species of tropical fish. Each year several children become interested enough in this study to work with him on certain aspects of it. He subscribes to journals in this field and has attended national conventions when they have met in his area. Other teachers in his school have similar interests related to other areas of science.

Our teachers of the future will have to work well together. At times, they may develop a team-teaching arrangement in which all children can benefit from the unique competencies of each teacher. However, the arrangement will be very flexible; they will move in and out of the team teaching arrangement as they decide which is the best way to develop their programs of education.

Our future teachers will work to help each child achieve optimum growth. About two-thirds of the children in our elementary classrooms of the future will have considerable aptitude for science. They will be encouraged to "stretch" as they study. The youngsters in the other third of the class, at this time, seem to have interests and aptitudes in other directions. They will be helped to develop a broad view of science. Our future elementary teachers will consider their primary function to be to help each child achieve his optimum intellectual, social, and physical growth, and they will know how to work with children to achieve this.

These teachers will teach in communities that care deeply for the education of their children. The members of the communities have become convinced that an individual's potentialities are profoundly affected by the kinds of educational experiences he receives early in life. The parents will be determined that their children shall receive the best possible education. As a result they will invest heavily in their schools, which are better than those in many other communities. Fortunately, there will be loud voices in other communities who will ask, "Why shouldn't our children have as good a chance in life as those in other school systems? Why should our children be cheated?" The school systems that develop exemplary programs contribute to the variety that is essential for the evolution of social institutions.

Every four or five years, our teachers of the future will devote a year to further study. The study often will not be done in colleges and universities; many aspects of their programs began to ossify beyond recall in the 1960's. While the university priesthood remains engaged in its rituals of meaningless research and time-wasting regurgitation, enterprising educators in government, industry, school systems, and in universities will organize institutes that actually consider problems that teachers and administrators face. Forward-looking school systems will have contracts with such institutes which make it possible for its teachers to engage periodically in further studies.

This brief description of teachers and teaching in the future has implications for our teacher-education programs. Most of the suggestions that follow are within our grasp, if we have the imagination and the will to strive for them.

EDUCATION IN SCIENCE FOR THE FUTURE TEACHERS

Hopefully, in the near future we will achieve a synthesis out of the many efforts that are underway in elementary-school science. The nature of this synthesis is already becoming apparent, with its implications for the kinds of education that future elementary school teachers should have in science. The future elementary school teacher should have fourteen years of science before undertaking the professional work in teacher education. In this work in science such matters as the following should be stressed:

(1) Future teachers should develop an understanding of the scientific view of man and his world. For example, these teachers should have a conceptual understanding of the conservation laws, and how they operate in the various sciences. Understandings from such sciences as cosmological astronomy, evolutionary biology, human physiology, and historical geology will be of special importance in developing this scientific view. The work in these areas of science should be planned to help students develop a modern, scientific view of the world. The needs of future professionals in these fields should be of secondary importance in these courses. However, these understandings in science are probably of importance to most people. A start has already been made in the development of such courses.

(2) The conceptual structure of science should be emphasized. Teachers will have firsthand experiences in developing operational definitions in science and in studying the interrelationships between definitions. They will study a variety of physical and biological systems and will develop operational concepts of the broad generalizations of science. In addition they should have experiences with a variety of interactions, become aware of the role of the observer in the study of phenomena, and gain some comprehension of the nature of evolution and revolution in scientific thought. The conceptual structure of science is of central importance in at least one science curriculum study, and teachers with some understanding of the nature and structure of science will be better prepared to work with children in such a program.

(3) There should be considerable emphasis upon the processes of science. The processes of science dealt with in teacher education will be somewhat different from those now being delineated for elementary-school science. Many of the processes dealt with in teacher education are related to scientific enterprise as contrasted to those of the individual scientists. These experiences will provide the intellectual foundations that will make it possible for teachers to achieve some of the potentials inherent in elementary science programs that emphasize process.

(4) A significant portion of the program of teacher education in science is devoted to the study of man. For some reason, there has been very little attention to the study of the man in our science-curriculum improvement projects. A project, somewhat like the man in our science-curriculum improvement projects. A project, somewhat like the Illinois Elementary School Science Project, focussing on the study of the human body, could make an important contribution. Certainly, teachers need some understanding of the area.

(5) Some systematic attention should be given to the interrelationships of science, technology, and society. Since science and technology may be among the greatest shapers of the future, it is essential that teachers have some understanding of these interrelationships.

The science courses which the future teacher takes will probably be developed cooperatively by scientists and science educators. Some such courses are already in a development stage.

However, much more emphasis will be given to individualized study, cooperatively planned with small committees of teacher educators. Development in this area has been slow because the books, programs, and other instructional materials have not been available in sufficient variety. By 1980 we should have them, and our instruction in science should become more efficient and effective.

It may be that considerable emphasis will be placed on science investigations that have relevance to elementary-school science. Laboratory and field investigations can be set up in which teachers have experiences in investigating science questions and problems to which answers are not known. For example, there are many questions related to the ecology of the local region that can be studied, such as the seasonal changes that take place in a small bog or the changes that take place over a period of time in an abandoned field or garden. In a sense, teachers would be carrying out original studies in which the answers are not known.

Such science investigations give teachers some firsthand experience in tackling problems in science. One of the possible disadvantages of a science program that stresses discrete processes of science is that the student may not recognize how these processes are interrelated. As they carry out science investigations, teachers have experiences in using various processes as they need them to deal with a question or problem. By 1980 it is to be hoped that we shall know much more about how to engage future teachers in such investigations.

ELEMENTARY SCIENCE METHODS

In their professional work in elementary school science, future teachers should learn how to work effectively with children in science. It is becoming more and more apparent that teaching style is of critical importance in science. Approaches to teaching that may conceivably be effective in some other areas of the curriculum are singularly inappropriate for science. Teaching style in science must be consistent with the nature of science as a human activity. Or, to put it negatively, science cannot be taught effectively in an unscientific way.

Science, for example, has an "endless frontier." Accomplishments great and small lead to new questions and more challenging problems. In fact, it has been suggested that the worth of scientific work be judged by the

nature and quality of the questions that are uncovered. The discovery that "inert" gases could be made to combine with other chemical elements was important, but the questions that were uncovered by this discovery were perhaps, of, greater importance. Future teachers should gain an appreciation for the questions uncovered by investigations in science. If science is characterized by an "endless frontier," how can it be taught in neat, tidy lessons which end in conclusions that tend to stifle further inquiry, rather than to encourage and stimulate it?

Science as an enterprise is a cumulative undertaking. We do know more now about certain aspects of our universe than did previous generations. In some science programs an almost completely heuristic approach is attempted; if the students did not already know better, they might be led to believe that nothing is known, and everything must be "discovered." In other programs almost total attention to the written word tends to inhibit inquiry rather than to support it. An important aspect of teaching style is to help students learn how to use the cumulative dimension of science as a resource, rather than as an inhibition of inquiry.

The nature of the teaching styles that are most effective for science instruction is being studied. By 1980, we shall know much more about them, as well as how to develop the teachers who will be able to use **effective teaching styles**.

More use will be made of diagnostic tools throughout education. With great mobility in population and inevitable loss of some school days because of sickness or travel, it will become more important to make periodic appraisals and prescriptions to overcome educational lacks. Diagnostic instruments are already under construction; more will be needed if we are to help teachers educate themselves.

The new tools becoming available for teacher education will aid the teacher in analyzing his own teaching. The video tape recorder has the potential of being used by teachers to analyze and improve their teaching styles. Films and tapes have long been used by football coaches to improve the performances of their teams; in a somewhat similar way they can be used to **improve teaching**.

We need to develop teaching simulators. This can conceivably be done with film, video tape, computer, and student response systems. The student will be presented with a teaching problem. He will be asked to respond to this problem as if he were the teacher of the class. He will then be shown the consequences when a teacher actually reacted in this way to such a problem. This will lead to further problems, and other reactions will be asked for. Highly sophisticated simulators have been used for a long time in flight instruction. Student response systems are already commercially available for use in schools. Teaching simulators with carefully prepared programs can be used to give students experiences with teaching problems before they move into the actual classroom.

Future teachers will give considerable time to preparation for the use of

new elementary science programs and materials. Naturally, this will involve examining the materials, "doing some of the experiments," and observing in schools where the programs are being used. However, this will not be enough. It is becoming apparent that the new programs depend very greatly upon the imagination and resourcefulness of the classroom teacher. Effective science teaching is not a step-by-step procedure; instead, it is an interaction between children, teacher, materials, equipment, and facilities. The teacher nurtures, stimulates, and guides these interactions. In order to do this effectively, the teacher needs foundational understanding of the new programs. In order to develop these understandings, specially designed teacher education programs will have to be prepared for use in conjunction with the new programs. The Science Curriculum Improvement Study (SCIS) is in the process of developing such a specially designed teacher education program. Our future teachers will have participated in one or two of these teacher-education programs. These experiences will provide them with the intellectual resources to recognize and develop some of the educational opportunities that arise in the use of the new programs.

Teachers will have some experience in using new teaching tools. Tele-conference and tele-consultation procedures will be used extensively in the teacher education programs. With them, future teachers can have direct contact with scientists and educators working at the frontiers of inquiry. The potentialities of these procedures have hardly been tapped. As they are used in teacher education, students will learn how to adapt them for use in elementary schools. Of course, the future teacher will be skilled in the use of radio, television, and all the various kinds of projectors. All of these devices are seen as ways of bringing the world of science into the classroom.

Students will also learn how to use efficient referral and retrieval systems. Information in the major libraries of the nation will be quickly available to teachers in school. Elementary-school teachers will also be able to get quick print-outs of procedures that can be used in their classrooms. Lack of information will no longer be a serious limiting factor. For example, the teacher who wishes to engage in studies of the instinctive behavior of sticklebacks will quickly be able to get the information necessary to launch the study. The programming of the elementary-science information that might be useful to classroom teachers will have absorbed a considerable fraction of the energies of the entire work force of science educators available in the late 1960's and early 1970's.

A great variety of educational procedures and materials will be available for teacher education, and a rigorous analysis will be made to choose those that will be most effective to achieve the ends that are desired. Much teacher education will be in the form of guided individual study. Very little teacher time will be used for the transmission of information.

Instead, precious teacher time will be used for the planning of individual programs of study, the consideration of laboratory investigations, analyses of teaching experiences, and discussions of thought-provoking ideas in education and science.

THEORETICAL FOUNDATIONS OF EDUCATION

By 1980, a rigorous reappraisal will have been made of the goals of education. The enrichment and enhancement of the life of each individual will be considered the central goal of education. The concern for the various academic disciplines will have declined. They will be viewed as being important only as they contribute to the lives of people. Similarly, societal demands will be appraised in terms of their contributions to individual development. Each individual human organism will be seen as having possibilities that formerly were not even imagined. The central function of the school, including the child's experiences in science, will be to stimulate and help the child to reach for his potentialities. As in science, course-content improvement programs in these areas will involve the cooperation of thoughtful teachers, professional educators, and academicians who have an insight into education.

It will have been shown beyond any reasonable doubt that children's early experiences during the pre-operational and concrete operational stages of intellectual development are of critical importance. It will be seen that if the child's very early years are intellectually sterile, his total development will be stunted. Experiences in science, with the emphasis upon multi-sensory experience with the concrete objects of the physical and biological environment, will be viewed as being of special importance in the education of young children. The recognition of the importance of early childhood education will lead some of our ablest young people to choose this area as their field of work.

The spirit of science will suffuse most areas of education. The publication of *Education and the Spirit of Science*¹ will be viewed as a landmark in the field. The characteristics of a rational person (longing to know and understand, questioning of all things, search for data and their meaning, demand for verification, respect for logic, consideration of premises, and consideration of consequences) suggested in this monograph give direction to the work in all areas of the curriculum.

LEADERSHIP IN ELEMENTARY SCHOOL SCIENCE

A major dimension in future teacher education in science will be the development of outstanding leaders who can give direction to developments in the field. These leaders in science education will be involved in the following five kinds of leadership functions:

(1) *Teacher education in science.* Most of these science educators will be involved in some way in educating teachers in science.

(2) *Research in science education.* Many science educators will be doing and directing research into some facets of science education.

(3) *Explainers and interpreters of science.* We are becoming more and more aware of the need for people who can explain and interpret science and scientists to children, teachers, and laymen. Many science educators will be involved in these endeavors.

(4) *Leaders in science curriculum development.* Since they have some understanding of science, schools, children, and the educative process, science educators will continue to give leadership in the never-ending task of perfecting our science curricula.

(5) *Consultants in science education.* The growing involvement of school systems, governmental agencies, and industry in science education will call for science educators to provide leadership in the areas of their expertise.

It may be recognized that these five functions serve to define the field of science education. By 1980, perhaps some of our leading institutions will have learned how better to prepare future science educators for these functions of leadership.

RESEARCH IN ELEMENTARY SCHOOL SCIENCE

Research will be accorded a more important role in elementary-school science education than it was in the 1960's; but it will be, to a large extent, a different kind of research. Too often, our research has been inconsequential; some almost appears to have been designed to make it possible to use complicated techniques. Rather than being masters of problems, we have been mastered by techniques. It is little wonder that very few pay much attention to science education research. In the 1960's, such research had very little influence and made few contributions to the improvement of the education of children. In the 1980's, it will be the most important avenue for the improvement of elementary science education.

One of the developments that will lead to greater significance of research will be the increased attention given to problem definition. It has been said that, "a problem well stated is half solved." There are no clear-cut steps toward problem definition; the most effective approach has been to become steeped in the problem situation. In elementary school science, this means gaining a profound understanding of issues in elementary school science, a thorough acquaintance with the literature, practical experience in working with children, and an awareness of some of the approaches that have been attempted in the past. The increased emphasis on problem definition will lead to research on more significant problems and to a growth in the public stature and teacher acceptance of science education research.

Some fascinating questions will be systematically studied:

"How do early firsthand experiences with science materials and objects affect the consequent intellectual development of the child?"

"How do new ideas in science education diffuse throughout the nation? What are obstacles to diffusion? How do various promising approaches to diffusion work?"

"Under what conditions will various ways of organizing elementary school science instruction be most effective?"

"Are there early science experiences that have a positive relationship with creativity in science? If so, what is the nature of these experiences?"

"What are effective ways of helping experienced teachers to make fundamental changes in their teaching styles?"

From a careful study of such questions we can expect improvement in elementary school science and in teacher education in science.

The increased emphasis on problem definition will make the research experience a much more important one for future learners in science education. There will be no more handing out of research problems by professors who want a job done. This action deprives the fledgling researcher of the most difficult and significant experience in educational research—the definition of the problem out of the confusion of the problem situation. The steeping of one's self in a problem situation in order to reach problem definition is probably one of the most important experiences for future leaders in science education.

Greater emphasis will be placed on cumulative research. It is recognized that every research study cannot begin at the beginning. Although they may not have 100 per cent acceptance in the science education fraternity, the results of some prior research will be accepted and further studies will be based upon them. For example, it will be agreed that there are a variety of effective approaches to working with children, and a series of studies will be conducted to discover the conditions and goals for which various approaches are most effective. This willingness to build research studies upon the results of prior studies will finally lead science education research into the natural history stage of development.

The results of research will be easily and quickly available to the researcher and to the practicing teacher. Printouts of all research results related to a specific question or problem may be obtained on short notice at centers throughout the nation, and hopefully, may help the teacher choose among various approaches to teaching.

TOMORROW

Our visions of tomorrow are limited by the blinders we wear today. Though our vision is limited, we try to see. Tomorrow will be shaped by many influences. As variety is important in evolution, it appears also to be important in the evolution of human enterprises. We can make a plea for

variety, because it will be through the interplay of a variety of influences that progress is made.

But, hopefully, we can give direction to the winds of change and try to shape a better tomorrow. As we peer ahead to 1980, we see pitfalls that can be avoided and opportunities that must not be missed. It is one of the functions of leaders in elementary science education to look ahead. Our look to the future provides a theoretical framework for our research and a base for our attempts to build a better education for future teachers and much more rewarding experiences in science for our children.

Reference

1. Educational Policies Commission, *Education and the Spirit of Science*, National Education Association, Washington, D.C., 1966.

INQUIRY AND PROCESS IN ELEMENTARY SCIENCE

INTRODUCTION

In the past few years a strong movement has gotten under way to change the emphasis in the teaching of science. This change in emphasis has to do with the objectives of science education and is associated, interestingly enough, with a difference of opinion about the proper definition of science. For a long time the standard definition of science has been "a body of systematized knowledge resulting from observation, study, and experimentation." Many scientists have objected strongly to this definition. They insist that science is "a process of inquiry, resulting in a body of systematized knowledge."

The two major objectives of science education are to help the child develop (1) knowledge of science concepts—the content of science—and (2) facility in scientific skills and attitudes—the processes of science and scientific inquiry. These objectives are essentially the same in the elementary and secondary school, the only difference being in how much and how well these objectives will be developed.

Science yearbooks, methods books, articles, and curriculum guides all have consistently urged for years that both objectives be given equal consideration when teaching science. Teachers have been encouraged to use the processes of science to achieve the learning of science content. However, all too often the major emphasis has been on content, and process has been ignored. This has resulted in memorization rather than thinking and in the learning of facts rather than concepts and principles. Furthermore, the children have been deprived of needed experiences with scientific inquiry and the processes of science.

It is easily understandable, then, why today there is widespread preoccupation with revising existing science programs and developing new programs in such a way that the process approach to the learning of science is stressed. The following are some of the key processes, or operations, of science and the scientist that are being suggested for inclusion in the elementary science program: observation, analysis, classification, description, interpretation, inference, induction, deduction,

hypothesis, prediction, planning, experimentation, designing of experiments, keeping of records, measurement, use of controls, and communication. Thus, concerted efforts are being made to bring the spirit as well as the substance of science into the classroom.

New knowledge of the ways children discover and learn, together with a re-discovery of psychological principles that had almost disappeared from view, are helping us decide the kind and amount of science that children should learn. We now know how the natural curiosity and investigative nature of the child can be utilized effectively to motivate inquiry and real science learning. We know that children go through a number of stages of intellectual development, in which the order of appearance of these stages does not vary. However, the time of appearance of these stages will vary with the individual child and with the society in which the child lives. We also know that we have underestimated greatly what children in the elementary school can learn.

This enthusiasm about the process approach to learning science has become so great that the pendulum is swinging the other way, and process is beginning to be emphasized at the expense of content. Some of the new programs are paying little attention to the learning of concepts. The science content in the program is almost completely unstructured, and whatever content that is included is used only as a means of getting the child to learn process. Many persons have already expressed some concern about this. They have strong reservations about the values claimed to be derived from teaching primarily for inquiry and from using only behaviorally stated objectives for curriculum planning. They claim that the dual objectives of content and process are of equal importance. They maintain that both objectives are not mutually exclusive, but are complementary and mutually interdependent. They contend that when we teach for content, the child should be learning process; and when we teach for process, the child should be learning content.

However, this overemphasis of process should not constitute any real cause for alarm. It helps bring strongly into focus the need for process as well as content in the teaching and learning of science. Eventually a happy medium of both process and content in elementary science should result.

PIAGET'S DEVELOPMENTAL THEORY OF LEARNING AND ITS IMPLICATIONS FOR INSTRUCTION IN SCIENCE*

Celia B. Stendler

Celia B. Stendler discusses Piaget's concept of intelligence, his concept of the properties of logical thinking, and his concept of stages in the development of logical thinking. Dr. Stendler points out that Piaget's concept of stages in logical thinking is not based upon ages but rather upon changes in the child's comprehension of logic. Dr. Stendler presents some promising leads about how the child develops logical thinking. Finally, she discusses the impact of early environmental deficits upon the culturally disadvantaged child. She sees the urgent need for systematic studies of the impact of cultural deprivation upon logical thinking.

I am going to begin with a few background remarks about Jean Piaget. Chances are that all of you are familiar with at least some of his work. He is, as you know, a Swiss psychologist who has been studying children for almost 50 years, and is still actively engaged in research at the Institute de J. J. Rousseau in Geneva. Those of you who are of my vintage may be best acquainted with his early work on language and moral development, first published in the twenties and still widely read. Even then Piaget's main concern was the epistemology. He asked and still asks, how does the child acquire knowledge, and what happens to mental processes during the acquisition? When his own children were infants, he made close observations and conducted little experiments with them, testing out his theory of how intelligence develops. Since then he has been busy refining theory and directing research, until today we have from his pen the best put-together picture of how intellectual development takes place. When Piaget talks about the development of intelligence, he means the development of logical thinking, which he regards as man's highest attribute. There are, of course, other aspects considered to be part of intelligence—memory, for example—but I will be talking today about logical intelligence when I use the term.

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All teachers, especially science and math teachers, must necessarily be concerned with logical thought processes in children. Many times throughout the day a teacher calls upon pupils to define, compare, contrast, find other examples of a phenomenon, deal with whole-part relations, and hypothesize. When a teacher asks a child to say what makes a bird a bird, or to give an example of adaptation, or to discover the relationship between angle of incidence and angle of reflection, he is calling upon the child to think logically, to perform some logical operations in thought. Note that such questions cannot be answered with responses learned through reinforcement. These questions require that the child manipulate data already stored in his mind, that he perform some mental operation to come up with his answer.

But what if the child cannot answer, or gives the wrong answer? What does the teacher do? Chances are he will call on another pupil, or he will say to the first, "Think! Think about my question. See if you can't find a better answer." Rarely does he ask, "How do you go about answering such a question?" to see if the pupil understands that *there are mental processes by which he can arrive at the correct answer*. More rarely still does he teach the pupil what that process is.

Note that I am using "process" in a different way from what you may be accustomed to. Bruner's book, *The Process of Education*, has popularized the word "process" in terms of the structure of subject matter, of the general principles that structure a body of knowledge. But *how* does a pupil grasp the principles? *How* does he make discoveries? When I talk about process, I have in mind what goes on in the gray cells that makes possible the acquisition of knowledge. It is process used in this sense that Piaget's theory is concerned with.

I have selected from the wealth of ideas that Piaget has given us three that I thought most relevant to the work of science educators. They are: Piaget's concept of intelligence; his concept of the properties of logical thought; and his concept of stages in the development of logical thinking. I will discuss each of these in turn.

First, his concept of intelligence. For Piaget, intelligence is not something that is qualitatively or quantitatively fixed at birth, but rather, is a form of adaptation characterized by equilibrium. Part of man's biological inheritance is a striving for equilibrium in *mental* processes as well as in other physiological processes. Two processes are involved: assimilation and accommodation. The child assimilates information from the environment which may upset existing equilibrium, and then accommodates present structures to the new so that equilibrium is restored. A six-year-old may think that cubes of sugar dropped into a jar of water will make the water level go up, but that after the sugar dissolves, the water level will go down again. But there is order in the physical world; as the child carries on interactions with things in his environment he gets feedback. At first when he sees that water level does NOT go down

when the sugar dissolves, he is shaken, but stumped. With repeated experiences and reflection upon outcome, he may come to see by eleven years that when we add something to a substance, it stays added. In the child's language, "Stuff doesn't go away by itself, you have to do something to it." The mental structure or schema involving conservation has been accommodated to the new information. Throughout the formative years, the child carries on countless transactions involving space, time, matter and causality, and as he assimilates information from the regularities in the physical world, old ideas are shaken and mental structures formed anew.

Note that the child must be mentally active; *he* must transform the data. In one demonstration session, I was testing a boy and girl together on a conservation of volume problem. Each child was presented with two cylinders identical in appearance, but one made of steel and the other of aluminum. No mention was made of weight, but the child held a cylinder in each hand and was asked to predict what each would do to the water level in the glasses, equal to begin with. The girl confidently predicted that the heavier one would make the water rise higher in the glass, the boy equally confidently predicted that water level would be the same. Then the cylinders were put in water and the girl's confidence was shaken. She had no explanation; *probably* she had been wrong, she thought. In the next step, the children were asked to find smaller objects that would make the water level go up the same as the steel cylinder. The girl chose heavy objects; the boy estimated overall size or volume. Then the girl reversed her decision. "He's probably right again," she said, "I'll say the same as he does; *but I don't really believe it*." This last remark is *most* revealing. As Piaget says over and over again, children do not acquire knowledge of something merely by being told or by reading about it, the child *must act upon it*. Acting upon it may or may not involve a physical action, but it must involve a mental action. When a physical action is needed is a problem that I hope our panel will address itself to.

The second part of Piaget's theory that I have chosen to talk about is his concept of the properties of logical thought. What do we do when we think logically? Let us look at a classroom example. A sixth grade class has been studying about the ways in which animals are adapted to their environment. The teacher asks, "Can you give me an example of an animal that lives in the desert, and explain how this is possible?" Assuming that the question is one that has not been dealt with directly in the text and so mere recall of information is not enough, what must a pupil do to answer the question? He has to manipulate data stored in his mind, shuffle different sets of facts around, or in Piaget's language, the child must perform some logical operations. First he may recall what extreme conditions with respect to basic needs of life are found on the desert and, second, select a particular desert animal and check out how that animal gets what it needs for survival under these extreme conditions. Let's take

the kangaroo rat. First we have a set of desert conditions, made up of "little water"; "extremes of temperature"; "scarcity of food"; "little ground cover." In the next set, we put the characteristics of the rat, "eats seeds and gets water from seeds"; "sharp claws and so burrows; stays underground during heat of day and so needs less water"; "eyes have many rods and so the animal can see to hunt for food at night when there is less competition and few enemies." In other words, we take the set of desert conditions and the set of kangaroo rat characteristics and we do a one-to-one correspondence between each. If for every member of one set there is a corresponding member in the other set, then we know the two sets are identical. When I talk about teaching children how to go about answering questions, I have in mind teaching them processes like this one.

Actually, there are two logical operations involved here. The first is to put together the elements making up each set. This operation is additive composition or combinativity. One of the properties of logical thought is that elements can be combined to make a total class; we can put two and two together figuratively as well as literally.

The second operation involved in the example of the kangaroo rat is an identity operation. You will recall that the child first postulated a set of conditions of desert life and then checked out known characteristics of the rat against these conditions by doing a one-to-one correspondence. Whenever we ask children to compare, contrast, or give an example of some concept, an identity operation is involved. Some pupils know how to perform such an identity operation; they know what must be done to see if two sets are identical. Others do not discover for themselves what mental process is necessary to get the right answer; they need to know that there is a process and what the steps in the process are.

Two additional properties of logical thinking are associativity and reversibility. One of the operations possible when we think logically is to put together elements in different ways to achieve the same result. This is associativity, which simply put, means that we can reach the same goal by different paths. In one of Piaget's tests the young child is shown two identical paths, each made up of rods of equal length. He is told that two dolls are going for a walk, one on each path. Does each doll take as long a walk as the other? Is each path as long? The child agrees that each is the same length. Then one of the paths is rearranged in zig-zag fashion and the question is repeated. The young child will think that now the straight path is longer, "for it goes way over to here," while by six or seven the child will say, "You've got the same sticks in each path and it doesn't matter how you put them. It'll be the same walk." Older children often use the associative principle in solving the displacement of water problem involving cylinders of different weights. Those who realize that the steel cylinder will displace exactly the same amount of water as the one made of aluminum will be able to select objects of various sizes and shapes to total approximately the same volume as the metal cylinders. They will say

of the one narrower in diameter, "It's skinnier, but it's longer. It makes up for being less here by being more here."

Of the displacements the child performs on data, one of the most critical to develop is that of reversibility. Every change, every displacement that we carry on mentally is reversible. We can combine robins and all birds-not-robins to make up a class of birds, and we can also separate the class into the original subclasses. We can construct hypotheses and then discard them and return to the starting point. We can follow one path in thinking and then retrace our steps without affecting the ideas employed. This ability to reverse thought is for Piaget the most clearly defined characteristic of logical intelligence.

The model that Piaget believes mirrors the thought of the child is a group-like structure or *groupement*. In fact, it is sometimes difficult to identify one of these logical properties in any mutually exclusive fashion for they are tightly knit ensembles. The child may say when one of the two balls of clay has been elongated, "They've got to be the same. Take some off the length and add it to the thickness and you're back where you started." He takes the data and puts them together in various ways to arrive at the solution to a problem.

Note, too, that the Piaget model is a logico-mathematical one. Those of you who are familiar with the principles of arithmetic as taught in the schools today will recognize in the four properties of thought the properties of algebraic structures. Piaget's model is a logico-mathematical one, for he sees the same structures in logical intelligence that have been identified in mathematics. The properties of the group correspond to the properties of thought in the child. In other words, mathematical structures and psychological structures resemble each other.

These operations that I have been describing characterize the thought processes of the child during the elementary school years, but during adolescence, there are changes that occur in modes of thinking. Piaget describes the kind of thinking that develops (and that, hopefully, characterizes adult thought) as *propositional thinking*. The child states propositions in terms of the variables he has identified, and then proceeds to systematically combine the propositions so as to test all possible combinations. A thirteen-year-old is presented with four flasks containing colorless, odorless liquids that look exactly the same, plus a bottle containing potassium iodide. He is shown that a few drops of the potassium iodide can turn the proper mixture of liquids yellow, and he is asked to reproduce the mixture. The boy's statements as he tries to solve the problem reveal certain characteristics of thinking that we do not find in younger children. For example, the boy states, "If this liquid (in the bottle) is water, then when you put it with a mixture of the first and third flasks it wouldn't prevent the yellow from forming." In effect, he is saying, "If it's water, it wouldn't do this"; one statement logically implies another.

There are four ways in which propositions can be combined. We can

combine by conjunction, as when we say, "It's got to be this *and* this"; by disjunction, "It's got to be this *or* this"; by negation, "It's neither this nor this"; and by implication, "If it's this, then this will be true." In addition to combining propositions in these four different ways, we can also transform each of the combinations in four different ways, yielding a possibility of sixteen different products. Let's suppose, for example, that you are interested in the problem of visual stimulation and whether design and/or color is more attractive to certain insects. How to combine the two variables? The possible combinations are:

Is it design and not color?

Is it color and not design?

Is it design and color?

Is it neither?

Each one of these questions must be systematically checked out. The various types of conjunctions and disjunctions must be continuously linked to implications. Suppose we start with "Is it design and not color?" Then we have to say, "If it's color and not design, then when we present both stimuli, we ought to attract more insects to the color." But note that immediately there are problems involving an identity transformation. If it's color, is it any color? Does red work as well as yellow? Do fluorescent colors work better than nonfluorescent? If it's the case that color red is equal to color yellow, the number of insects should be the same. Back and forth the mind goes, combining propositions and then performing operations upon the propositions like identity operation that we just illustrated. Or the operation may be one of negation, of reciprocity or of correlation. "A change in the amount of fluorescence in the paint is going to result in a corresponding change in number of insects caught" is a statement of correlation. "If I vary designs from simple to complex and still don't attract as many insects as with color, then it can't be design" is an example of negation.

Propositional thinking is what our science teaching should help to develop; and again I would urge that we can best develop propositional thinking by letting pupils in on the fact that there *is* a set of operations consistently used in logical thinking. Students should *know* that there *are* systematic ways in which we combine propositions for testing hypotheses, and they should know what these systematic ways are. We have given lip service to the scientific method by teaching that children should observe carefully, state hypotheses, test hypotheses, note results, and come to some kind of conclusion. But notice the holes in such a procedure. We teach the importance of observation, but the *young* child *is* an observer. He does indeed observe carefully, but he judges in terms of perceptual data, of how things look to him, instead of performing logical operations on the data. And we emphasize stating and testing hypotheses without giving any clues as to how we can combine propositions and test *so as to exclude as well as to include*. Some so-called experiments are set up so

that the child never has a chance to state as a proposition what he really thinks makes a difference. A third grade class was observing a demonstration in which lighted candles were covered with jars of various sizes and the children correctly hypothesized that the taller jar would provide more air and so the candle would burn longer. Usually this particular demonstration stops with the testing of the correct hypothesis. But the smart teacher in this case knew that there was a prior question: what determines the amount of air in the jar? Would the number of candles burning under each jar make a difference? This question gave the children no difficulty; they could state the case correctly. Then the teacher asked what else *might* make a difference? What about height of candle? Would a tall candle go out more quickly than a short one? The answer for the third-graders was yes! Demonstration and experimentation must be carried on so as to test for the exclusion of variables as well as to test the significant one that *we* know works.

So much, then, for an overview of what is involved in logical thinking. Now we turn to the developmental process. How do logical operations develop in the child? For Piaget the development of intelligence begins at least in the cradle and goes through stages from birth to maturity. The first stage Piaget calls the sensori-motor. The infant comes into the world with two kinds of reflexes: those like the knee jerk that are not altered by experience, and others like grasping and sucking that *are* modified as the infant exercises them. The modification occurs through assimilation and accommodation. The infant, for example, accommodates the grasping reflex to the shape of the object to be grasped, curving his fingers one way for a long narrow object, and in a different way for a ring. During the first eighteen months, the infant carries on countless transactions involving space, time, matter, and causality which build and reshape developing mental structures. Witness what happens with respect to the notion of permanence of object. To the neonate, the game of peek-a-boo is meaningless; for him, an object ceases to exist when it disappears from view, and out-of-sight is out-of-mind. But later in the first year, the infant knows that an object continues to exist and delights in searching for it when it is hidden. He "knows," not in words, but in his sensori-motor system, in much the same way that we may "know" how to find our way through a building the second time. For Piaget, sensori-motor intelligence is the intelligence of action. The infant must first carry out displacements in his actions, searching for an object first in one place and then in another, for he cannot do this in his mind. However, physical actions gradually become internalized, and by eighteen months the child is capable of "representation," of imagining the environment other than as he directly perceives it.

I move quickly to the next stage, the pre-operational, which extends from eighteen months, roughly, to about seven years. It is in this stage that we find most kindergarten and first-grade children, some second-grade, and of course, some children even older than seven years. This stage

is called pre-operational because the child does not use logical operations in his thinking. Piaget characterizes mental processes at the pre-operational stage as follows:

1. The child is perceptually oriented; he makes judgments in terms of how things *look* to him. He may, for example, be confused in thinking about space by the objects placed in that space. When given a problem where two lines of ten segmented sticks are laid out in parallel rows, he will see that both are equal in length; that two dolls, walking along each path, would walk the same distance. But if one of the rows is rearranged in this fashion:



and the child is again asked if each doll takes as long a walk as the other, the child says "no." Even when he counts the segments, he denies equality; the child does not see that there is a logical necessity by which ten must equal ten. Piaget has shown that this same type of perceptual judgment enters into the child's thinking about space, time, number and causality. It is only as the child goes beyond his perceptions to perform displacements upon the data in his mind (for example, visualizing the second row of sticks straightened out again) that conservation appears.

2. The child centers on one variable only, and usually the variable that stands out visually; he lacks the ability to coordinate variables. A kindergarten child is pouring juice into paper cups. The standard size cups run out, and the teacher substitutes some that are much higher but are also smaller in diameter. As the children drink their juice, several comment on the fact that Jimmy, Eddie, and Danny have more juice. And why? Because their cups are taller. The dimension of height stands out, not that of width, in this case. The child's thinking is rigid; he does not perform operations on what he sees. Later he will reason that "higher than" is compensated for by "skinnier than" and that both kinds of cups may hold the same amount of juice. This ability to see reciprocal changes in two sets of data is an important logical tool available to older children but not in the pre-operational child.

3. The child has difficulty in realizing that an object can possess more than one property, and that multiplicative classifications are possible. It is hard for the child to see that one can live in Champaign and in Illinois at the same time; that a bird is also an animal; and that an Impala is also a Chevy. The operation of combining elements to form a whole and then seeing a part in relation to the whole has not as yet developed, and so hierarchical relationships cannot be mastered.

So far, this consideration of pre-operational thinking has been largely negative. We have seen that the child lacks the ability to combine parts into a whole, to put parts together in different ways, and to reverse processes. What, then, can the child do? The development of logical processes is not at a standstill during this period, and there are some positive accomplishments. We see, for example, the rudiments of classification; the child can make collections of things on the basis of

some criterion. He can also shift that criterion. Thus, if we present a kindergarten child with a collection of pink and blue squares and circles, some large and some small, and ask him to sort them into two piles with those in each pile being alike in some way, he can usually make two different collections on the basis of color and shape (a few children discover the third criterion of size). Such an ability, of course, is essential to the formation of classes and eventually to the notion of hierarchy of classes. Science provides countless opportunities for having children discover more than one variable. Sounds, for example, can be high or low, loud or soft, to make four possible combinations, as shown on this matrix.

The child is also beginning to arrange things in a series. He can compare two members of a set within a series when they are in consecutive order; he knows that Tuesday comes after Monday. But since Friday comes after Tuesday, which is after Monday, does Friday also come after Monday? This operation involving seeing logical relations between things or events that are arranged in a series is not yet possible to the pre-operational child, but experiences with seriation are preparatory to the development of such operations.

By seven years of age, the logical operations of reversibility, associativity, etc., that I have already described begin to appear. Piaget calls this the stage of concrete operations, because while the child uses logical operations, the content of his thinking is concrete rather than abstract. Fifth-grade pupils, if given a billiard-game problem when they are studying light, can do serial ordering and establish a one-to-one correspondence between the two slopes of directions. "The more I put it like that (inclined to the right), the more the ball will go like that," a ten-year-old will explain. That the total angle can be divided into two equal angles does not occur to them, for they lack the formal operations necessary to such a discovery. They solve problems and give explanations in terms of the concrete data available to them; they do not try to state generalizations.

This stage of concrete operations lasts until 12 years which is roughly the age for the onset of the state of formal operations or propositional thinking. According to Piaget, most children at the high school level tend to do the "If this happens, then that is likely to happen," or not to happen, kind of thinking. They are also more likely to think in terms of abstractions and can state, as in the case of the billiard game, the general principle involved.

Critics of Piaget have made his notion of development as occurring in stages one of their targets. Some mistakenly think that Piaget uses the concept as does Gesell. For Piaget, however, stages are convenient for helping us to think coherently about the course of development. His descriptions of stages are based upon changes in the child's comprehension of logic. They are not tied in any hard-and-fast way to age. In fact, as the students in Geneva discovered when they tried the Piaget tasks on husbands or wives, or other adults including themselves, adults are spotty in their ability to solve the tasks. With respect to cognitive processes at

each of the stages, Piaget describes these in terms of probability; he would say that at a particular stage there is a probability which can be set at a certain figure that the child will select a particular strategy for solving a problem. Thus, when the ball of clay is transformed into a sausage, there is a strong probability that the child will at one stage mention length rather than thickness, and an even stronger probability that he won't think of two dimensions.

The question arises, once we assume that stages in logical thinking are not rigidly tied to age, as to whether we can then speed up the development of logical thinking. This is a question that never fails to amuse students and faculty in Geneva, for they regard it as typically American. Tell an American that a child develops certain ways of thinking at seven, and he immediately sets about to try to develop those same ways of thinking at six or even five years of age. Actually investigators in countries other than America have tried to accelerate the development of logical thinking, and we have available today a considerable body of research on what works and what doesn't work. Most of the research has not worked. It hasn't worked because experimenters have not paid attention to equilibrium theory. The researchers have tried to teach an answer, a particular response, rather than to develop operations. They have tried to teach the child that of course the hot dog will weigh as much as the clay ball; just put both on a two-pan-balance and you'll see. But the child is completely unconvinced unless he shuffles the data around in his mind, using one or more of the operations I've described. Learning a fact by reinforcement does not in and of itself result in mental adaptation.

What does work? Research by some investigators (Smedslund and Wohlwill in particular) offers some promising leads. These might be summarized as follows:

1. It has been possible to accelerate the development of logical intelligence by inducing cognitive conflict in subjects. Smedslund devised a training procedure with the balls of clay where he both elongated the clay and also took away a piece of it, thus forcing the child to choose between two conflicting explanations. Can the hot dog weigh more when a piece has been taken away? Given this kind of choice, the child veers toward consistency.
2. Training children to recognize that an object can belong to several different classes at once aids in the development of logical classification.
3. There is a tendency for children, trained to see that addition and subtraction of elements changes numerical value to achieve conservation earlier than a non-trained group.
4. To help children move from the pre-operational stage to the stage of concrete operations, it is helpful to make gradual transformations in the visual stimulus, and to call the child's attention to the effects of a change in one dimension to a change in another.

There is a fifth possibility that I'd like to suggest, and that is that children, as they study subject-matter, should also be alerted to *process* in terms of the logical operations that I have been describing. At the present time, I am working on a research project in University City, Missouri, sponsored by the Ford Foundation. We are trying to introduce more intellectual stimulation into the kindergarten curriculum. Kindergartens, as you know, do a very good job for the most part in helping the child adjust to group life and to school routines. They also provide many fine activities designed to foster creativity. But kindergartens haven't quite known what to do to stimulate intellectual development. Some have turned to the teaching of reading, but the actual process of learning to read, while of course essential, does not really involve much in the way of logical thinking. In University City we are giving children equipment and opportunity to work with equipment designed to help them develop logical multiplication (that is, that an object can belong to several classes at once), the concept of a grid system, matrix-type thinking, the concept of unit iteration in measurement, and certain other processes. Underlying these processes, is the group-structure I have described. After five months when all 400 children have had a chance to play with equipment, to act upon it, we will give training on the operations themselves to part of the group. We have controls in another community. We will then be able to compare children's performance after six months of working on Piaget tasks with children without such experience. We will also be able to compare a smaller group of children who have received special training with a group that has experienced free play with Piaget tasks but no training. My subjective judgment is that the free play is effective.

A word in closing about the culturally disadvantaged. The evidence is overwhelming that early environmental deficits leave their impact upon the developing organism. Years ago, Goldforb found that children who spent the first three years of their lives in foundling institutions were deficient in concept development and in language, and since that time, as one writer has noted, there is a dreary repetition to the studies finding over and over again mental deficits resulting from environmental deprivation.

Poverty contributes to environmental deprivation. That "the poor are segregated and have no chance to learn from their more fortunate neighbors" was observed by Mme. Montessori in the Roman slums in 1907; it is just as true today. Poverty is not always accompanied by environmental deprivation; some families in America with low incomes manage to provide children with an environment conducive to development of intelligence, but this only happens when parents themselves have had an opportunity to know that a different way of life is possible, and to have some idea of how their children might achieve what they missed. The history of immigrant families in America attests to the truth of this generalization. Nor is poverty the only prerequisite to cultural deprivation. There are rural families and blue-collar families who are above the

subsistence level, but whose home environment is at such a low cultural level that the children are essentially culturally deprived when they enter school and have learning problems.

We have been in home after home of the culturally disadvantaged where there are no books, no toys, nothing for small children to do except to look for hours at the ever-present television set or carry on boisterous play with their siblings. Piaget talks about logical intelligence developing as the child carries on transactions upon objects or events in the environment. Thus, children acquire notions of the world of space, time, matter and causality, have their notions jarred and have equilibrium restored at a higher level, all this in what we have assumed to be a *normal* pattern of living. But today the voices of Luci and Desi and Andy Griffith and *As the World Turns* provide the stuff to stretch children's minds. Small wonder that we find these minds are not developing as they should and that there are nine- and ten-year-olds who are not mentally retarded, but who are still at the pre-operational level in logical thinking. There are no systematic studies of the development of logical thinking in culturally disadvantaged children. In Champaign-Urbana, however, we have administered the Piaget tests to more than 100 poor children in the last three years and the retardation is obvious. When we ask a nine-year-old boy, for example, to look at a set of geometric figures (circles, squares and triangles) in two sizes and colors, and to separate them into two piles, putting those in one pile that go together in some way, he can classify by one criterion (shape, most likely), but he cannot see that one can group in terms of color and also of size. Language is, of course, a handicap. Seven-year-olds sometimes don't know what we're talking about when we use terms like "top" and "bottom," "up" and "down." Shown a bottle half filled with water and then turned on its side, the child is asked, "How high-up is the water now?" It is the word "up" in the question that bothers the child. Interestingly enough, however, these children often do better in problems involving operations upon relations than they do those involving operations upon classes. When we deal with class concepts, language becomes a handicap, but when we present the child with a cube $3 \times 3 \times 4$ and ask him to make a "house" on a 1×3 base with just as many "rooms" out of one-inch blocks, the child reveals that he is using logical operations such as combining elements, seeing more than one dimension and it may be that in certain areas of thinking cultural deprivation takes a stronger toll than in others. We need systematic studies of the impact of cultural deprivation upon logical thinking so that we can provide for the problem of match.

In closing I would like to say that while I hope I have made Piaget's theory clearer to most of you, I believe firmly with Piaget that more than sitting and listening is necessary for accommodation to occur. I would urge you for a fuller understanding to administer some of the Piaget tests yourselves to children. Listen to the answers that children give to the

standard questions and one will be forever humbled by the knowledge that in teaching one often fails to hit upon the very elementary but very basic misunderstanding that is interfering with logical thinking. Today we pride ourselves in science teaching that the curriculum is stronger in respectable subject-matter than ever before. Let's make sure that we aren't trying to teach atomic theory to children who have not yet grasped the conservation principle in its simplest form.

READINESS FOR LEARNING*

Jerome S. Bruner

The following article consists of key excerpts from Chapter III of Jerome S. Bruner's book, 'The Process Of Education. Dr. Bruner proposes his widely quoted hypothesis that "any subject can be taught effectively in some intellectually honest form to any child at any stage of development." To clarify the implications of this hypothesis, he examines three general ideas: the process of intellectual development in children, the act of learning, and the notion of the "spiral curriculum." All three ideas have broad significance for curriculum development.

We begin with the hypothesis that any subject can be taught effectively in some intellectually honest form to any child at any stage of development. It is a bold hypothesis and an essential one in thinking about the nature of a curriculum. No evidence exists to contradict it; considerable evidence is being amassed that supports it.

To make clear what is implied, let us examine three general ideas. The first has to do with the process of intellectual development in children, the second with the act of learning, and the third with the notion of the "spiral curriculum" introduced earlier.

INTELLECTUAL DEVELOPMENT. Research on the intellectual development of the child highlights the fact that at each stage of development the child has a characteristic way of viewing the world and explaining it to himself. The task of teaching a subject to a child at any particular age is one of representing the structure of that subject in terms

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of the child's way of viewing things. The task can be thought of as one of translation. The general hypothesis that has just been stated is premised on the considered judgment that any idea can be represented honestly and usefully in the thought forms of children of school age, and that these first representations can later be made more powerful and precise the more easily by virtue of this early planning. To illustrate and support this view, we present here a somewhat detailed picture of the course of intellectual development, along with some suggestions about teaching at different stages of it.

The work of Piaget and others suggests that, roughly speaking, one may distinguish three stages in the intellectual development of the child. The first stage need not concern us in detail, for it is characteristic principally of the pre-school child. In this stage, which ends (at least for Swiss school children) around the fifth or sixth year, the child's mental work consists principally in establishing relationships between experience and action; his concern is with manipulating the world through action. This stage corresponds roughly to the period from the first development of language to the point at which the child learns to manipulate symbols. In this so-called preoperational stage, the principal symbolic achievement is that the child learns how to represent the external world through symbols established by simple generalization; things are represented as equivalent in terms of sharing some common property. But the child's symbolic world does not make a clear separation between internal motives and feelings on the one hand and external reality on the other. The sun moves because God pushes it, and the stars, like himself, have to go to bed. The child is little able to separate his own goals from the means for achieving them, and when he has to make corrections in his activity after unsuccessful attempts at manipulating reality, he does so by what are called intuitive regulations rather than by symbolic operations, the former being of a crude trial-and-error nature rather than the result of taking thought.

What is principally lacking at this stage of development is what the Geneva school has called the concept of reversibility. When the shape of an object is changed, as when one changes the shape of a ball of plasticene, the preoperational child cannot grasp the idea that it can be brought back readily to its original state. Because of this fundamental lack the child cannot understand certain fundamental ideas that lie at the basis of mathematics and physics—the mathematical idea that one conserves quantity even when one partitions a set of things into subgroups, or the physical idea that one conserves mass and weight even though one transforms the shape of an object. It goes without saying that teachers are severely limited in transmitting concepts to a child at this stage, even in a highly intuitive manner.

The second stage of development—and now the child is in school—is called the stage of concrete operations. This stage is operational in

contrast to the preceding stage, which is merely active. An operation is a type of action: it can be carried out rather directly by the manipulation of objects, or internally, as when one manipulates the symbols that represent things and relations in one's mind. Roughly, an operation is a means of getting data about the real world into the mind and there transforming them so that they can be organized and used selectively in the solution of problems. Assume a child is presented with a pinball machine which bounces a ball off a wall at an angle. Let us find out what he appreciates about the relation between the angle of incidence and the angle of reflection. The young child sees no problem: for him, the ball travels in an arc, touching the wall on the way. The somewhat older child, say age ten, sees the two angles as roughly related—as one changes so does the other. The still older child begins to grasp that there is a fixed relation between the two, and usually says it is a right angle. Finally, the thirteen- or fourteen-year-old, often by pointing the ejector directly at the wall and seeing the ball come back at the ejector, gets the idea that the two angles are equal. Each way of looking at the phenomenon represents the result of an operation in this sense, and the child's thinking is constrained by his way of pulling his observations together.

An operation differs from simple action or goal-directed behavior in that it is internalized and reversible. "Internalized" means that the child does not have to go about his problem-solving any longer by overt trial and error, but can actually carry out trial and error in his head. Reversibility is present because operations are seen as characterized where appropriate by what is called "complete compensation"; that is to say, an operation can be compensated for by an inverse operation. If marbles, for example, are divided into subgroups, the child can grasp intuitively that the original collection of marbles can be restored by being added back together again. The child tips a balance scale too far with a weight and then searches systematically for a lighter weight or for something with which to get the scale rebalanced. He may carry the reversibility too far by assuming that a piece of paper, once burned, can also be restored.

With the advent of concrete operations, the child develops an internalized structure with which to operate. In the example of the balance scale the structure is a serial order of weights that the child has in his mind. Such internal structures are of the essence. They are the internalized symbolic systems by which the child represents the world, as in the example of the pinball machine and the angles of incidence and reflection. It is into the language of these internal structures that one must translate ideas if the child is to grasp them.

But concrete operations, though they are guided by the logic of classes and the logic of relations, are means for structuring only immediately present reality. The child is able to give structure to the things he encounters, but he is not yet readily able to deal with possibilities not directly before him or not already experienced. This is not to say that

children operating concretely are not able to anticipate things that are not present. Rather, it is that they do not command the operations for conjuring up systematically the full range of alternative possibilities that could exist at any given time. They cannot go systematically beyond the information given them to a description of what else might occur. Somewhere between ten and fourteen years of age the child passes into a third stage, which is called the stage of "formal operations" by the Geneva school.

Now the child's intellectual activity seems to be based upon an ability to operate on hypothetical propositions rather than being constrained to what he has experienced or what is before him. The child can now think of possible variables and even deduce potential relationships that can later be verified by experiment or observation. Intellectual operations now appear to be predicated upon the same kinds of logical operations that are the stock in trade of the logician, the scientist, or the abstract thinker. It is at this point that the child is able to give formal or axiomatic expression to the concrete ideas that before guided his problem-solving but could not be described or formally understood.

Earlier, while the child is in the stage of concrete operations, he is capable of grasping intuitively and concretely a great many of the basic ideas of mathematics, the sciences, the humanities, and the social sciences. But he can do so only in terms of concrete operations. It can be demonstrated that fifth-grade children can play mathematical games with rules modeled on highly advanced mathematics; indeed, they can arrive at these rules inductively and learn how to work with them. They will flounder, however, if one attempts to force upon them a formal mathematical description of what they have been doing, though they are perfectly capable of guiding their behavior by these rules. At the Woods Hole Conference we were privileged to see a demonstration of teaching in which fifth-grade children very rapidly grasped central ideas from the theory of functions, although had the teacher attempted to explain to them what the theory of functions was, he would have drawn a blank. Later, at the appropriate stage of development and given a certain amount of practice in concrete operations, the time would be ripe for introducing them to the necessary formalism.

What is most important for teaching basic concepts is that the child be helped to pass progressively from concrete thinking to the utilization of more conceptually adequate modes of thought. But it is futile to attempt this by presenting formal explanations based on a logic that is distant from the child's manner of thinking and sterile in its implications for him. Much teaching in mathematics is of this sort. The child learns not to understand mathematical order but rather to apply certain devices or recipes without understanding their significance and connectedness. They are not translated into his way of thinking. Given this inappropriate start,

he is easily led to believe that the important thing is for him to be "accurate"—though accuracy has less to do with mathematics than with computation. Perhaps the most striking example of this type of thing is to be found in the manner in which the high school student meets Euclidian geometry for the first time, as a set of axioms and theorems, without having had some experience with simple geometric configurations and the intuitive means whereby one deals with them. If the child were earlier given the concepts and strategies in the form of intuitive geometry at a level that he could easily follow, he might be far better able to grasp deeply the meaning of the theorems and axioms to which he is exposed later.

But the intellectual development of the child is no clockwork sequence of events; it also responds to influences from the environment, notably the school environment. Thus, instruction in scientific ideas, even at the elementary level, need not follow slavishly the natural course of cognitive development in the child. It can also lead intellectual development by providing challenging but usable opportunities for the child to forge ahead in his development. Experience has shown that it is worth the effort to provide the growing child with problems that tempt him into next stages of development. As David Page, one of the most experienced teachers of elementary mathematics, has commented: "In teaching from kindergarten to graduate school, I have been amazed at the intellectual similarity of human beings at all ages, although children are perhaps more spontaneous, creative, and energetic than adults. As far as I am concerned young children learn almost anything faster than adults do if it can be given to them in terms they understand. Giving the material to them in terms they understand, interestingly enough, turns out to involve knowing the mathematics oneself, and the better one knows it, the better it can be taught. It is appropriate that we warn ourselves to be careful of assigning an absolute level of difficulty to any particular topic. When I tell mathematicians that fourth-grade students can go a long way into 'set theory' a few of them reply: 'Of course.' Most of them are startled. The latter ones are completely wrong in assuming that 'set theory' is intrinsically difficult. Of course it may be that nothing is intrinsically difficult. We just have to wait until the proper point of view and corresponding language for presenting it are revealed. Given particular subject matter or a particular concept, it is easy to ask trivial questions, or to lead the child to ask trivial questions. It is also easy to ask impossibly difficult questions. The trick is to find the medium questions that can be answered and that take you somewhere. This is the big job of teachers and textbooks." One leads the child by the well-wrought "medium questions" to move more rapidly through the stages of intellectual development, to a deeper understanding of mathematical, physical, and historical principles. We must know far more about the ways in which this can be done.

THE ACT OF LEARNING. Learning a subject seems to involve three almost simultaneous processes. First there is *acquisition* of new information—often information that runs counter to or is a replacement for what the person has previously known implicitly or explicitly. At the very least it is a refinement of previous knowledge. Thus one teaches a student Newton's laws of motion, which violate the testimony of the senses. Or in teaching a student about wave mechanics, one violates the student's belief in mechanical impact as the sole source of real energy transfer. Or one bucks the language and its built-in way of thinking in terms of "wasting energy" by introducing the student to the conservation theorem in physics which asserts that no energy is lost. More often the situation is less drastic, as when one teaches the details of the circulatory system to a student who already knows vaguely or intuitively that blood circulates.

A second aspect of learning may be called *transformation*—the process of manipulating knowledge to make it fit new tasks. We learn to "unmask" or analyze information, to order it in a way that permits extrapolation of interpolation or conversion into another form. Transformation comprises the ways we deal with information in order to go beyond it.

A third aspect of learning is *evaluation*: checking whether the way we have manipulated information is adequate to the task. Is the generalization fitting, have we extrapolated appropriately, are we operating properly? Often a teacher is crucial in helping with evaluation, but much of it takes place by judgments of plausibility without our actually being able to check rigorously whether we are correct in our efforts.

In the learning of any subject matter, there is usually a series of episodes, each episode involving the three processes. Photosynthesis might reasonably comprise material for a learning episode in biology, fitted into a more comprehensive learning experience such as learning about the conversion of energy generally. At its best a learning episode reflects what has gone before it and permits one to generalize beyond it.

A learning episode can be brief or long, contain many ideas or a few. How sustained an episode a learner is willing to undergo depends upon what the person expects to get from his efforts, in the sense of such external things as grades but also in the sense of a gain in understanding.

We usually tailor material to the capacities and needs of students by manipulating learning episodes in several ways: by shortening or lengthening the episode, by piling on extrinsic rewards in the form of praise and gold stars, or by dramatizing the shock of recognition of what the material means when fully understood. The unit in a curriculum is meant to be a recognition of the importance of learning episodes, though many units drag on with no climax in understanding. There is a surprising lack of research on how one most wisely devises adequate learning episodes for children at different ages and in different subject matters.

THE "SPIRAL CURRICULUM." If one respects the ways of thought of the growing child, if one is courteous enough to translate material into his logical forms and challenging enough to tempt him to advance, then it is possible to introduce him at an early age to the ideas and styles that in later life make an educated man. We might ask, as a criterion for any subject taught in primary school, whether, when fully developed, it is worth an adult's knowing, and whether having known it as a child makes a person a better adult. If the answer to both questions is negative or ambiguous, then the material is cluttering the curriculum.

If the hypothesis with which this section was introduced is true—that any subject can be taught to any child in some honest form—then it should follow that a curriculum ought to be built around the great issues, principles, and values that a society deems worthy of the continual concern of its members.

If the understanding of number, measure, and probability is judged crucial in the pursuit of science, then instruction in these subjects should begin as intellectually honestly and as early as possible in a manner consistent with the child's forms of thought. Let the topics be developed and redeveloped in later grades. Thus, if most children are to take a tenth-grade unit in biology, need they approach the subject cold? Is it not possible, with a minimum of formal laboratory work if necessary, to introduce them to some of the major biological ideas earlier, in a spirit perhaps less exact and more intuitive?

Many curricula are originally planned with a guiding idea much like the one set forth here. But as curricula are actually executed, as they grow and change, they often lose their original form and suffer a relapse into a certain shapelessness. It is not amiss to urge that actual curricula be reexamined with an eye to the issues of continuity and development referred to in the preceding pages. One cannot predict the exact forms that revision might take; indeed, it is plain that there is now available too little research to provide adequate answers. One can only propose that appropriate research be undertaken with the greatest vigor and as soon as possible.

THE ACT OF DISCOVERY*

Jerome S. Bruner

Jerome S. Bruner believes that it is only through the exercise of problem-solving and the effort of discovery that one learns the working heuristics of discovery; and the more one has practice, the more likely is one to generalize what one has learned into a style of inquiry that serves for any kind of task. Dr. Bruner discusses what the act of discovery entails. He also describes four major benefits derived by children when they learn how to investigate and discover for themselves: (1) an increase in intellectual potency, (2) a shift from extrinsic to intrinsic rewards, (3) learning the heuristics of discovery, and (4) aid in memory processing.

Maimonides, in his *Guide for the Perplexed*,¹ speaks of four forms of perfection that men might seek. The first and lowest form is perfection in the acquisition of worldly goods. The great philosopher dismisses such perfection on the ground that the possessions one acquires bear no meaningful relation to the possessor: "A great king may one morning find that there is no difference between him and the lowest person." A second perfection is of the body, its conformation and skills. Its failing is that it does not reflect on what is uniquely human about man: "he could (in any case) not be as strong as a mule." Moral perfection is the third, "the highest degree of excellency in man's character." Of this perfection Maimonides says: "Imagine a person being alone, and having no connection whatever with any other person; all his good moral principles are at rest, they are not required and give man no perfection whatever. These principles are only necessary and useful when man comes in contact with others." The fourth kind of perfection is "the true perfection of man; the possession of the highest intellectual faculties..." In justification of his assertion, this extraordinary Spanish-Judaic philosopher urges: "Examine the first three kinds of perfection; you will find that if you possess them, they are not your property, but the property of others. . . . But the last kind of perfection is exclusively yours; no one else owns any part of it."

It is a conjecture much like that of Maimonides that leads me to

* REPRINTED FROM *Harvard Educational Review*, Vol. 31, No. 1, 1961, pp. 21-32, by permission of the author and the publisher. Dr. Bruner is Professor of Psychology and Director of the Center for Cognitive Studies at Harvard University.

¹ Maimonides, *Guide for the Perplexed* (New York: Dover Publications, 1956).

examine the act of discovery in man's intellectual life. For if man's intellectual excellence is the most his own among his perfections, it is also the case that the most uniquely personal of all that he knows is that which he has discovered for himself. What difference does it make, then, that we encourage discovery in the learning of the young? Does it, as Maimonides would say, create a special and unique relation between knowledge possessed and the possessor? And what may such a unique relation do for a man—or for a child, if you will, for our concern is with the education of the young?

The immediate occasion for my concern with discovery—and I do not restrict discovery to the act of finding out something that before was unknown to mankind, but rather include all forms of obtaining knowledge for oneself by the use of one's own mind—the immediate occasion is the work of the various new curriculum projects that have grown up in America during the last six or seven years. For whether one speaks to mathematicians or physicists or historians, one encounters repeatedly an expression of faith in the powerful effects that come from permitting the student to put things together for himself, to be his own discoverer.

First, let it be clear what the act of discovery entails. It is rarely, on the frontier of knowledge or elsewhere, that new facts are "discovered" in the sense of being encountered as Newton suggested in the form of islands of truth in an uncharted sea of ignorance. Or if they appear to be discovered in this way, it is almost always thanks to some happy hypotheses about where to navigate. Discovery, like surprise, favors the well prepared mind. In playing bridge, one is surprised by a hand with no honors in it at all and also by hands that are all in one suit. Yet all hands in bridge are equiprobable: one must know to be surprised. So, too, in discovery. The history of science is studded with examples of men "finding out" something and not knowing it. I shall operate on the assumption that discovery, whether by a schoolboy going it on his own or by a scientist cultivating the growing edge of his field, is in its essence a matter of rearranging or transforming evidence in such a way that one is enabled to go beyond the evidence so reassembled to additional new insights. It may well be that an additional fact or shred of evidence makes this larger transformation of evidence possible. But it is often not even dependent on new information.

It goes without saying that, left to himself, the child will go about discovering things for himself within limits. It also goes without saying that there are certain forms of child rearing, certain home atmospheres that lead some children to be their own discoverers more than other children. These are both topics of great interest, but I shall not be discussing them. Rather, I should like to confine myself to the consideration of discovery and "finding-out-for-oneself" within an educational setting—especially the school. Our aim as teachers is to give our student as firm a grasp of a subject as we can, and to make him as autonomous and self-propelled a thinker as we can—one who will go along

on his own after formal schooling has ended. I shall return in the end to the question of the kind of classroom and the style of teaching that encourage an attitude of wanting to discover. For purposes of orienting the discussion, however, I would like to make an overly simplified distinction between teaching that takes place in the *expository mode* and teaching that utilizes the *hypothetical mode*. In the former, the decisions concerning the mode and pace and style of exposition are principally determined by the teacher as expositor; the student is the listener. If I can put the matter in terms of structural linguistics, the speaker has a quite different set of decisions to make than the listener: the former has a wide choice of alternatives for structuring, he is anticipating paragraph content while the listener is still intent on the words, he is manipulating the content of the material by various transformations while the listener is quite unaware of these internal manipulations. In the hypothetical mode, the teacher and the student are in a more cooperative position with respect to what in linguistics would be called "speaker's decisions." The student is not a bench-bound listener, but is taking a part in the formulation and at times may play the principal role in it. He will be aware of alternatives and may even have an "as if" attitude toward these, and as he receives information he may evaluate it as it comes. One cannot describe the process in either mode with great precision as to detail, but I think the foregoing may serve to illustrate what is meant.

Consider now what benefit might be derived from the experience of learning through discoveries that one makes for oneself. I should like to discuss these under four headings: (1) The increase in intellectual potency, (2) the shift from extrinsic to intrinsic rewards, (3) learning the heuristics of discovering, and (4) the aid to memory processing.

1. INTELLECTUAL POTENCY. If you will permit me, I would like to consider the difference between subjects in a highly constrained psychological experiment involving a two-choice apparatus. In order to win chips, they must depress a key either on the right or the left side of the machine. A pattern of payoff is designed such that, say, they will be paid off on the right side 70 per cent of the time, on the left 30 per cent, although this detail is not important. What is important is that the payoff sequence is arranged at random, and there is no pattern. I should like to contrast the behavior of subjects who think that there *is* some pattern to be found in the sequence—who think that regularities are discoverable—in contrast to subjects who think that things are happening quite by *chance*. The former group adopts what is called an "event-matching" strategy in which the number of responses given to each side is roughly equal to the proportion of times it pays off: in the present case R70:L30. The group that believes there is no pattern very soon reverts to a much more primitive strategy wherein *all* responses are allocated to the side that has the greater payoff. A little arithmetic will show you that the lazy all-and-none strategy pays off more if indeed the environment is random:

namely, they win seventy per cent of the time. The event-matching subjects win about 70 per cent on the 70 per cent payoff side (or 49 per cent of the time there) and 30 per cent of the time on the side that pays off 30 per cent of the time (another 9 per cent for a total take-home wage of 58 per cent of the time (another 9 per cent for a total take-home is not always or not even frequently random, and if one analyzes carefully what the event-matchers are doing, it turns out that they are trying out hypotheses one after the other, all of them containing a term such that they distribute bets on the two sides with a frequency to match the actual occurrence of events. If it should turn out that there is a pattern to be discovered, their payoff would become 100 per cent. The other group would go on at the middling rate of 70 per cent.

What has this to do with the subject at hand? For the person to search out and find regularities and relationships in his environment, he must be armed with an expectancy that there will be something to find and, once aroused by expectancy, he must devise ways of search and finding. One of the chief enemies of such expectancy is the assumption that there is nothing one can find in the environment by way of regularity or relationship. In the experiment just cited, subjects often fall into a habitual attitude that there is either nothing to be found or that they can find a pattern by looking. There is an important sequel in behavior to the two attitudes, and to this I should like to turn now.

We have been conducting a series of experimental studies on a group of some seventy school children over the last four years. The studies have led us to distinguish an interesting dimension of cognitive activity that can be described as ranging from *episodic empiricism* at one end to *cumulative constructionism* at the other. The two attitudes in the choice experiments just cited are illustrative of the extremes of the dimension. I might mention some other illustrations. One of the experiments employs the game of Twenty Questions. A child—in this case he is between 10 and 12—is told that a car has gone off the road and hit a tree. He is to ask questions that can be answered by "yes" or "no" to discover the cause of the accident. After completing the problem, the same task is given him again, though he is told that the accident had a different cause this time. In all, the procedure is repeated four times. Children enjoy playing the game. They also differ quite markedly in the approach or strategy they bring to the task. There are various elements in the strategies employed. In the first place, one may distinguish clearly between two types of questions asked: the one is designed for locating constraints in the problem, constraints that will eventually give shape to an hypothesis; the other is the hypothesis as question. It is the difference between, "Was there anything wrong with the driver?" and "Was the driver rushing to the doctor's office for an appointment and the car got out of control?" There are children who precede hypotheses with efforts to locate constraint and there are those who, to use our local slang, are "pot-shotters," who string

out hypotheses non-cumulatively one after the other. A second element of strategy is its connectivity of information gathering: the extent to which questions asked utilize or ignore or violate information previously obtained. The questions asked by children tend to be organized in cycles, each cycle of questions usually being given over to the pursuit of some particular notion. Both within cycles and between cycles one can discern a marked difference on the connectivity of the child's performance. Needless to say, children who employ constraint location as a technique preliminary to the formulation of hypotheses tend to be far more connected in their harvesting of information. Persistence is another feature of strategy, a characteristic compounded on what appear to be two components: a sheer doggedness component, and a persistence that stems from the sequential organization that a child brings to the task. Doggedness is probably just animal spirits or the need for achievement—what has come to be called *n-ach*. Organized persistence is a maneuver for protecting our fragile cognitive apparatus from overload. The child who has flooded himself with disorganized information from unconnected hypotheses will become discouraged and confused sooner than the child who has shown a certain cunning in his strategy of getting information—a cunning whose principal component is the recognition that the value of information is not simply in getting it but in being able to carry it. The persistence of the organized child stems from his knowledge of how to organize questions in cycles, how to summarize things to himself, and the like.

Episodic empiricism is illustrated by information gathering that is unbound by prior constraints, that lacks connectivity, and that is deficient in organizational persistence. The opposite extreme is illustrated by an approach that is characterized by constraint sensitivity, by connective maneuvers, and by organized persistence. Brute persistence seems to be one of those gifts from the gods that make people more exaggeratedly what they are.²

Before returning to the issue of discovery and its role in the development of thinking, let me say a word more about the ways in which information may get transformed when the problem solver has actively processed it. There is first of all a pragmatic question: what does it take to get information processed into a form best designed to fit some future use? Take an experiment by Zajonc³ as a case in point. He gives groups of subjects information of a controlled kind, some groups being told that their task is to transmit the information to others, others that it is merely

² I should also remark in passing that the two extremes also characterize concept attainment strategies as reported in *A Study of Thinking* by J. S. Bruner et al. (New York: J. Wiley, 1956). Successive scanning illustrates well what is meant here by episodic empiricism; conservative focusing is an example of cumulative constructionism.

³ R. B. Zajonc (Personal communication, 1957).

to be kept in mind. In general, he finds more differentiation and organization of the information received with the intention of being transmitted than there is for information received passively. An active set leads to a transformation related to a task to be performed. The risk, to be sure, is in possible overspecialization of information processing that may lead to such a high degree of specific organization that information is lost for general use.

I would urge now in the spirit of an hypothesis that emphasis upon discovery in learning has precisely the effect upon the learner of leading him to be a constructionist, to organize what he is encountering in a manner not only designed to discover regularity and relatedness, but also to avoid the kind of information drift that fails to keep account of the uses to which information might have to be put. It is, if you will, a necessary condition for learning the variety of techniques of problem solving, of transforming information for better use, indeed for learning how to go about the very task of learning. Practice in discovering for oneself teaches one to acquire information in a way that makes that information more readily viable in problem-solving. So goes the hypothesis. It is still in need of testing. But it is an hypothesis of such important human implications that we cannot afford not to test it—and testing will have to be in the schools.

2. *INTRINSIC AND EXTRINSIC MOTIVES.* Much of the problem in leading a child to effective cognitive activity is to free him from the immediate control of environmental rewards and punishments. That is to say, learning that starts in response to the rewards of parental or teacher approval or the avoidance of failure can too readily develop a pattern in which the child is seeking cues as to how to conform to what is expected of him. We know from studies of children who tend to be early over-achievers in school that they are likely to be seekers after the "right way to do it" and that their capacity for transforming their learning into viable thought structures tends to be lower than children merely achieving at levels predicted by intelligence tests. Our tests on such children show them to be lower in analytic ability than those who are not conspicuous in overachievement.⁴ As we shall see later, they develop rote abilities and depend upon being able to "give back" what is expected rather than to make it into something that relates to the rest of their cognitive life. As Maimonides would say, their learning is not their own.

The hypothesis that I would propose here is that to the degree that one is able to approach learning as a task of discovering something rather than "learning about" it, to that degree will there be a tendency for the child to carry out his learning activities with the autonomy of self-reward or more properly by reward that is discovery itself.

⁴ J. S. Bruner and A. J. Caron, "Cognition, Anxiety, and Achievement in the Preadolescent," *Journal of Educational Psychology* (in press).

To those of you familiar with the battles of the last half-century in the field of motivation, the above hypothesis will be recognized as controversial. For the classic view of motivation in learning has been, until very recently, couched in terms of a theory of drives and reinforcement: that learning occurred by virtue of the fact that a response produced by a stimulus was followed by the reduction in a primary drive state. The doctrine is greatly extended by the idea of secondary reinforcement: any state associated even remotely with the reduction of a primary drive could also have the effect of producing learning. There has recently appeared a most searching and important criticism of this position, written by Professor Robert White,⁵ reviewing the evidence of recently published animal studies, of work in the field of psychoanalysis, and of research on the development of cognitive processes in children. Professor White comes to the conclusion, quite rightly I think, that the drive-reduction model of learning runs counter to too many important phenomena of learning and development to be either regarded as general in its applicability or even correct in its general approach. Let me summarize some of his principal conclusions and explore their applicability to the hypothesis stated above.

I now propose that we gather the various kinds of behavior just mentioned, all of which have to do with effective interaction with the environment, under the general heading of competence. According to Webster, competence means fitness or ability, and the suggested synonyms include capability, capacity, efficiency, proficiency, and skill. It is, therefore, a suitable word to describe such things as grasping and exploring, crawling and walking, attention and perception, language and thinking, manipulating and changing the surroundings, all of which promote an effective a competent-interaction with the environment. It is true, of course, that maturation plays a part in all these developments, but this part is heavily overshadowed by learning in all the more complex accomplishments like speech or skilled manipulation. I shall argue that it is necessary to make competence a motivational concept; there is *competence motivation* as well as competence in its more familiar sense of achieved capacity. The behavior that leads to the building up of effective grasping, handling, and letting go of objects, to take one example, is not random behavior that is produced by an overflow of energy. It is directed, selective, and persistent, and it continues not because it serves primary drives, which indeed it cannot serve until it is almost perfected, but because it satisfies an intrinsic need to deal with the environment.⁶

I am suggesting that there are forms of activity that serve to enlist and develop the competence motive, that serve to make it the driving force behind behavior. I should like to add to White's general premise that the *exercise* of competence motives has the effect of strengthening the degree to which they gain control over behavior and thereby reduce the effects of extrinsic rewards or drive gratification.

⁵ R. W. White, "Motivation Reconsidered: The Concept of Competence," *Psychological Review*, LXVI (1959), pp. 297-333.

⁶ *Ibid.*, pp. 317-318.

The brilliant Russian psychologist Vigotsky⁷ characterizes the growth of thought processes as starting with a dialogue of speech and gesture between child and parent; autonomous thinking begins at the stage when the child is first able to internalize these conversations and "run them off" himself. This is a typical sequence in the development of competence. So, too, in instruction. The narrative of teaching is of the order of the conversation. The next move in the development of competence is the internalization of the narrative and its "rules of generation" so that the child is now capable of running off the narrative on his own. The hypothetical mode in teaching by encouraging the child to participate in "speaker's decisions" speeds this process along. Once internalization has occurred, the child is in a vastly improved position from several obvious points of view—notably that he is able to go beyond the information he has been given to generate additional ideas that can either be checked immediately from experience or can, at least, be used as a basis for formulating reasonable hypotheses. But over and beyond that, the child is now in a position to experience success and failure not as reward and punishment, but as information. For when the task is his own rather than a matter of matching environmental demands, he becomes his own paymaster in a certain measure. Seeking to gain control over his environment, he can now treat success as indicating that he is on the right track, failure as indicating he is on the wrong one.

In the end, this development has the effect of freeing learning from immediate stimulus control. When learning in the short run leads only to pellets of this or that rather than to mastery in the long run, then behavior can be readily "shaped" by extrinsic rewards. When behavior becomes more long-range and competence-oriented, it comes under the control of more complex cognitive structures, plans and the like, and operates more from the inside out. It is interesting that even Pavlov—whose early account of the learning process was based entirely on a notion of stimulus control of behavior through the conditioning mechanism in which, through contiguity, a new conditioned stimulus was substituted for an old unconditioned stimulus by the mechanism of stimulus substitution—that even Pavlov recognized his account as insufficient to deal with higher forms of learning. To supplement the account, he introduced the idea of the "second signalling system," with central importance placed on symbolic systems such as language in mediating and giving shape to mental life. Or as Luria⁸ has put it, "the first signal system [is] concerned with directly perceived stimuli, the second with systems of verbal elaboration." Luria commenting on the importance of the transition from first to second signal system says: "It would be mistaken to suppose that verbal intercourse with adults merely changes the contents of the child's

⁷ L. S. Vigotsky, *Thinking and Speech* (Moscow, 1934).

⁸ A. L. Luria, "The Directive Function of Speech in Development and Dissolution," *Word*, XV (1959), pp. 341-464.

conscious activity without changing its form. . . . The word has a basic function not only because it indicates a corresponding object in the external world, but also because it abstracts, isolates the necessary signal, generalizes perceived signals and relates them to certain categories; it is this systematization of direct experience that makes the role of the word in the formation of mental processes so exceptionally important."^{9,10}

It is interesting that the final rejection of the universality of the doctrine of reinforcement in direct conditioning came from some of Pavlov's own students. Ivanov-Smolensky¹¹ and Krasnogorsky¹² published papers showing the manner in which symbolized linguistic messages could take over the place of the unconditioned stimulus and of the unconditioned response (gratification of hunger) in children. In all instances, they speak of these as *replacements* of lower, first-system mental or neural processes by higher order or second-system controls. A strange irony, then, that Russian psychology that gave us the notion of the conditioned response and the assumption that higher order activities are built up out of colligations or structurings of such primitive units, rejected this notion while much of American learning psychology has stayed until quite recently within the early Pavlovian fold (see, for example, a recent article by Spence¹³ in the *Harvard Educational Review*, or Skinner's treatment of language¹⁴ and the attacks that have been made upon it by linguists such as Chomsky¹⁵ who have become concerned with the relation of language and cognitive activity). What is the more interesting is that Russian pedagogical theory has become deeply influenced by this new trend and is now placing much stress upon the importance of building up a more active symbolical approach to problem-solving among children.

To sum up the matter of the control of learning, then, I am proposing that the degree to which competence or mastery motives comes to control behavior, to that degree the role of reinforcement or "extrinsic pleasure" wanes in shaping behavior. The child comes to manipulate his environment more actively and achieves his gratification from coping with problems. Symbolic modes of representing and transforming the

⁹ *Ibid.*, p. 12.

¹⁰ For an elaboration of the view expressed by Luria, the reader is referred to the forthcoming translation of L. S. Vigotsky's 1934 book being published by John Wiley and Sons and the Technology Press.

¹¹ A. G. Ivanov-Smolensky, "Concerning the Study of the Joint Activity of the First and Second Signal Systems," *Journal of Higher Nervous Activity*, 1, (1951), p. 1.

¹² N. D. Krasnogorsky, *Studies of Higher Nervous Activity in Animals and in Man*, Vol. 1 (Moscow, 1954).

¹³ K. W. Spence, "The Relation of Learning Theory to the Technique of Education," *Harvard Educational Review*, XXIX (1959), pp. 84-95.

¹⁴ B. F. Skinner, *Verbal Behavior* (New York: Appleton-Century-Crofts, 1957).

¹⁵ N. Chomsky, *Syntactic Structure* (The Hague, The Netherlands. Mouton & Co., 1957).

environment arise and the importance of stimulus-response-reward sequences declines. To use the metaphor that David Riesman developed in a quite different context, mental life moves from a state of outer-directedness in which the fortuity of stimuli and reinforcement are crucial to a state of inner-directedness in which the growth and maintenance of mastery become central and dominant.

3. *LEARNING THE HEURISTICS OF DISCOVERY.* Lincoln Steffens,¹⁶ reflecting in his *Autobiography* on his undergraduate education at Berkeley, comments that his schooling was overly specialized on learning about the known and that too little attention was given to the task of finding out about what was not known. But how does one train a student in the techniques of discovery? Again I would like to offer some hypotheses. There are many ways of coming to the arts of inquiry. One of them is by careful study of its formalization in logic, statistics, mathematics, and the like. If a person is going to pursue inquiry as a way of life, particularly in the sciences, certainly such study is essential. Yet, whoever has taught kindergarten and the early primary grades or has had graduate students working with him on their theses I choose the two extremes for they are both periods of intense inquiry—knows that an understanding of the formal aspect of inquiry is not sufficient. There appear to be, rather, a series of activities and attitudes, some directly related to a particular subject and some of them fairly generalized, that go with inquiry and research. These have to do with the *process* of trying to find out something, and while they provide no guarantee that the *product* will be any *great* discovery, their absence is likely to lead to awkwardness or aridity or confusion. How difficult it is to describe these matters—the heuristics of inquiry. There is one set of attitudes or ways of doing that has to do with sensing the relevance of variables—how to avoid getting stuck with edge effects and getting instead to the big sources of variance. Partly this gift comes from intuitive familiarity with a range of phenomena, sheer “knowing the stuff.” But it also comes out of a sense of what things among an ensemble of things “smell right” in the sense of being of the right order of magnitude or scope or severity.

The English philosopher, Weldon, describes problem-solving in an interesting and picturesque way. He distinguishes between difficulties, puzzles, and problems. We solve a problem or make a discovery when we impose a puzzle form on to a difficulty that converts it into a problem that can be solved in such a way that it gets us where we want to be. That is to say, we recast the difficulty into a form that we know how to work with, then work it. Much of what we speak of as discovery consists of knowing how to impose what kind of form on various kinds of difficulties. A small part but a crucial part of discovery of the highest

¹⁶ L. Steffens, *Autobiography of Lincoln Steffens* (New York: Harcourt Brace, 1931).

order is to invent and develop models or "puzzle forms" that can be imposed on difficulties with good effect. It is in this area that the truly powerful mind shines. But it is interesting to what degree perfectly ordinary people can, given the benefit of instruction, construct quite interesting and what, a century ago, would have been considered greatly original models.

Now to the hypothesis. It is my hunch that it is only through the exercise of problem-solving and the effort of discovery that one learns the working heuristics of discovery, and the more one has practice, the more likely is one to generalize what one has learned into a style of problem solving or inquiry that serves for any kind of task one may encounter—or almost any kind of task. I think the matter is self-evident, but what is unclear is what kinds of training and teaching produce the best effects. How do we teach a child to, say, cut his losses but at the same time be persistent in trying out an idea; to risk forming an early hunch without at the same time formulating the one so early and with so little evidence as to be stuck with it waiting for appropriate evidence to materialize, to pose good testable guesses that are neither too brittle nor too sinuously incorrigible. Practice in inquiry, in trying to figure out things for oneself, is indeed what is needed, but in what form? Of only one thing I am convinced. I have never seen anybody improve in the art and technique of inquiry by any means other than engaging in inquiry.

4. *CONSERVATION OF MEMORY.* I should like to take what some psychologists might consider a rather drastic view of the memory process. It is a view that in large measure derives from the work of my colleague, Professor George Miller.¹⁷ Its first premise is that the principal problem of human memory is not storage, but retrieval. In spite of the biological unlikeliness of it, we seem to be able to store a huge quantity of information—perhaps not a full tape recording, though at times it seems we even do that, but a great sufficiency of impressions. We may infer this from the fact that recognition (i.e., recall with the aid of maximum prompts) is so extraordinarily good in human beings—particularly in comparison with spontaneous recall where, so to speak, we must get out stored information without external aids or prompts. The key to retrieval is organization or, in even simpler terms, knowing where to find information and how to get there.

Let me illustrate the point with a simple experiment. We present pairs of words to twelve-year-old children. One group is simply told to remember the pairs, that they will be asked to repeat them later. Another is told to remember them by producing a word or idea that will tie the pair together in a way that will make sense to them. A third group is given the

¹⁷ G. A. Miller, "The Magical Number Seven, Plus or Minus Two," *Psychological Review*, LXIII (1956), pp. 81-97.

mediators used by the second group when presented with the pairs to aid them in tying the pairs into working units. The word pairs include such juxtapositions as "chair-forest," "sidewalk-square," and the like. One can distinguish three styles of mediators and children can be scaled in terms of their relative preference for each: *generic mediation* in which a pair is tied together by a superordinate idea: "chair and forest are both made of wood"; *thematic mediation* in which the two terms are imbedded in a theme or little story: "the lost child sat on a chair in the middle of the forest", and *part-whole mediation* where "chairs are made from trees in the forest" is typical. Now, the chief result, as you would all predict, is that children who provide their own mediators do best—indeed, one time through a set of thirty pairs, they recover up to 95 per cent of the second words when presented with the first ones of the pairs, whereas the uninstructed children reach a maximum of less than 50 per cent recovered. Interestingly enough, children do best in recovering materials tied together by the form of mediator they most often use.

One can cite a myriad of findings to indicate that any organization of information that reduces the aggregate complexity of material by imbedding it into a cognitive structure a person has constructed will make that material more accessible for retrieval. In short, we may say that the process of memory, looked at from the retrieval side, is also a process of problem-solving: how can material be "placed" in memory so that it can be got on demand?

We can take as a point of departure the example of the children who developed their own technique for relating the members of each word pair. You will recall that they did better than the children who were given by exposition the mediators they had developed. Let me suggest that in general, material that is organized in terms of a person's own interests and cognitive structures is material that has the best chance of being accessible in memory. That is to say, it is more likely to be placed along routes that are connected to one's own ways of intellectual travel.

In sum, the very attitudes and activities that characterize "figuring out" or "discovering" things for oneself also seem to have the effect of making material more readily accessible in memory.

THE LEARNING REQUIREMENTS FOR ENQUIRY*

Robert M. Gagné

Robert M. Gagné agrees with other authors that enquiry is a necessary and vital objective of science instruction. He maintains, however, that if the practice of enquiry is to be carried out successfully, there are two major prerequisites: (1) a suitable background of broad generalized knowledge, which can be used in solving problems to make the inductive leap that characterizes enquiry, and (2) the possession of incisive knowledge, which makes it possible to discriminate between a good idea and a bad one. Dr. Gagné believes that, as the child progresses from kindergarten through college, there should be four levels of instruction which would enable the child to become progressively a competent performer, a student of knowledge, a scientific enquirer, and an independent investigator. There is constant overlap in the competencies and capabilities that are acquired at each level of instruction.

One of the most interesting and important ideas which has been given emphasis in recent discussions of science education is the idea of enquiry. It has been stated to be perhaps the most critical kind of activity that the scientist engages in, and for that reason to represent one of the most essential objectives of science instruction. Accordingly, there appears to be a very widespread agreement that enquiry is a worthwhile objective—something that our various educational efforts should deliberately try to achieve. And there is a widespread consensus that an instructional program for the student of science most clearly achieves this rightful goal when it enables such a student to adopt the procedures of scientific enquiry in response to any new unsolved problem he encounters.

Along with this emphasis on the importance of the method of enquiry there has been an accompanying realization that many traditional courses in science, at all levels of education, exhibit serious deficiencies insofar as they fail to get across to students the elements of this method. Many such courses seem to be neglecting the student in the most important sense that they do not encourage him to acquire the attitudes of enquiry, the

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methods of enquiry, the understanding of enquiry. They may provide him with a great many facts, with knowledge of important principles, even with the capability of using previously discovered principles in situations novel to him. But they omit this essential part of his education as a scientist, or even as an informed citizen, by not establishing within him the disposition which makes him able to employ enquiry in the manner so well-known to scientists.

Perhaps no writer has described this deficiency in science education so cogently and so thoroughly as has Schwab. It is worthwhile to quote here a short passage from his *Inglis Lecture*:¹

It is the almost total absence of this portrayal of science which marks the greatest disparity between science as it is and science as seen through most textbooks of science. We are shown conclusions of enquiry as if they were certain or nearly certain facts. Further, we rarely see these conclusions as other than isolated, independent "facts." Their coherence and organization—the defining marks of *scientific knowledge*—are underemphasized or omitted. And we catch hardly a glimpse of the other constituents of scientific enquiry: organizing principles, data, and the interpretation of data.

The problem, then, seems pretty well-defined and agreed upon. It is, "How can one go about introducing, or perhaps restoring, to the process of instruction the necessary conditions which will make it more probable that the student learns about science as enquiry?" Obviously this is not as simple a matter as is "adding material" on neutrinos in atomic structure, or even as is "revising material" such as that on the reactivity of inert chemical elements. It is more complicated than either of these, because it is more difficult to identify and specify what it is that the student must learn. Yet this is the task that must be faced, complicated or not, if the desired change is to be brought about.

Let us assume, then, that there is general agreement about the problem and about the objective to be sought in its solution. Now, what, if anything, can the methods and results of research on the learning process contribute to this problem? This is the interest of the student of learning theory. Obviously, dealing with science as enquiry must be something that is learned. What do we know about learning that is relevant in establishing such a capability in the student?

ANALYSIS OF THE PROBLEM

As is the case with other users of scientific methods, the investigator of human learning customarily begins by defining or specifying what the problem is in terms which have served this function in the past. These terms serve to separate the general aspects of the problem situation from

¹ See References.—Eds.

the specific and therefore incidental ones, and thus enable him to think about it in a rigorous fashion.

When this basic method is applied to the problem, the first distinction which becomes apparent is this: First, there is something we may call a *terminal capability*, something that the student is able to do after he has learned. That is to say, if we have been successful in establishing the correct conditions for learning, we will be able to infer that the student is or is not capable of employing the methods of scientific enquiry. To make this inference possible, of course, we must observe some kinds of behavior, which may also be specified, and we might refer to these observed events as *terminal behaviors*.

Second, the other major category of events with which we must deal in this problem is a set of conditions which are used to bring about a *change* in the student's capability. These we may call the *instructional conditions*. Potentially, these conditions include everything that is done to or by the student from some initial point in time (when he does not possess the desired capability) to some other point in time (when he does). But more specifically, they are all the aspects of the instructional situation which can be shown to affect this change, including the events that take place in classrooms, laboratories, libraries, at his desk, or elsewhere.

Perhaps this distinction seems obvious to you—the terminal capability, on the one hand, and the instructional conditions which accomplish the change between initial and terminal capability, on the other. But this distinction has not always been carefully maintained in thinking about this problem, even by people who think profoundly about it. It is nonetheless an essential distinction, and one which will be referred to again later.

THE TERMINAL CAPABILITY

In order to understand and specify the problem further, we need to ask again, what is the nature of this desired capability of using the approach of enquiry towards the solution of problems? Having read the authors who have written on this subject, one concludes that they have spent many more words describing what it is *not* than in describing what it *is*. What it is not, all agree, is an activity which deals with scientific concepts as things rather than abstractions, or with scientific hypotheses and theories as fixed facts rather than as convenient models subject to empirical test. I judge them to mean, that what it *is* is a set of activities characterized by a problem-solving approach, in which each newly encountered phenomenon becomes a challenge for thinking. Such thinking begins with a careful set of systematic observations, proceeds to design the measurements required, clearly distinguishes between what is observed and what is inferred, invents interpretations which are under ideal circumstances brilliant leaps, but always testable, and draws

reasonable conclusions. In other words, it is the kind of activity that might be called the essence of scientific research (neglecting for the moment such clearly relevant components as obtaining research funds and writing good scientific reports, among others).

Can such inferred capabilities as these be observed as behavior? It does not seem unreasonable that this is possible, provided we accept the fact that the sample of behavior we may be able to observe is somewhat limited and therefore somewhat unreliable. This appears to be the kind of behavior the university science faculty tries to observe in its graduate students. It uses various methods of doing this, such as requiring the execution of an initial problem before the dissertation, or requiring the completion of a series of partial problems, or by asking the student to "think through" how he would approach an already reported investigation, or in some other manner. In many instances, more and better observation of this sort could actually be done, if some greater thought were given to it.

Observation of such behavior is also done with increasing frequency at the undergraduate college level. Here we find programs of independent study, honors programs, and other devices which require students to take an independent approach of enquiry towards a scientific problem. Again, the frequency and representativeness of this kind of observation of "enquiry behavior" can be improved. A number of authors suggest, for example, that the laboratory be made the setting for the practice of this approach, by designing and using the kinds of laboratory problems which are invitations to careful thought, rather than "standard exercises."

Can this kind of activity of scientific enquiry be extended downward to the secondary school and even into the primary grades? Of course it can, in some sense, since we know that even elementary students are quite capable of some pretty good thinking. But whether it should or not may involve some other considerations which we have not yet touched upon.

CONDITIONS OF INSTRUCTION

We are now ready to look more closely at the other part of the problem—how do we effect a change such that a student who doesn't initially employ the approach of enquiry toward problems will employ this approach? What are the conditions of instruction which are likely to effect this change?

PRACTICE IN ENQUIRY

One of the conditions emphasized by several writers on this question is that of *practicing strategies* in proceeding from the known to the unknown. Bruner,² for example, calls this "learning the heuristics of

discovery," and states that although the form that such learning should take is not known in detail, it seems reasonable that improvement in the technique of enquiry should depend upon practice in enquiry. Schwab¹ points out the ways that such practice can be conducted in the laboratory and in the classroom. The import of these writings for the design of instructional conditions is clear: the student should be provided with opportunities to carry out inductive thinking; to make hypotheses and to test them, in a great variety of situations, in the laboratory, in the classroom, and by his own individual efforts.

It is impossible not to agree with this prescription in a specific sense. The student who has been given practice merely in the recall of ideas, or in their application in particular situations, will not necessarily acquire these important techniques of enquiry. In physics, for example, the setting of problems like this one is a common practice in many textbooks: "A box slides down a 30° inclined plane with an acceleration of 10 ft./sec.² What is the coefficient of friction between the box and the plane? Now the student obviously is getting practice from performing such problems, but the question is, what kind of practice? Obviously not the same kind he would get if this kind of problem were stated: "A box slides down an inclined plane. Can this event be shown to be compatible with Newton's second law of motion?" In this second case, what is being required of the student is that he relate some observed events to a general principle (or "law"), and that he himself *think out* what these relationships are. First he must identify the forces at work, specify the mass and acceleration, and then induce how these specific variables may be related to the general equation $F = ma$. And in carrying out this enquiry, he is obtaining valuable practice which will doubtless be transferable to other problems, not necessarily within the field of physics alone. A similar technique, or thinking strategy, may be useful in quite a different situation—in thinking about the reactions of chemical solutions, or about the metabolism of a cell, or even about the relation of national income to productivity.

If there are any limitations to the value of *practice in enquiry*, they are probably to be found in this fact: such practice is *not the whole story*. Establishing conditions for practice in enquiry does not by any means exhaust the requirements for the instructional conditions needed for the achievement of the desired terminal capability. And there are real dangers in thinking that such practice does constitute the entire set of requirements for this purpose.

Some scholars have perceived this danger. In a recent interview recorded in the newspapers, the noted physicist Dr. C. N. Yang³ states his concern about the increasingly common practice of starting students on basic research early in their college careers. Students who are educated in this way, he says, will not be able to stand away from their work and see it in

perspective; they will think of research as a study of a single problem rather than as a broad attack on the entire frontier of the unknown. In dealing with new problems, such students will lack the deep understanding on which to draw for help.

Dr. Yang's concern is essentially the same as that just mentioned. There is nothing wrong with practicing enquiry, and surely enquiry is the kind of capability we want students of science to attain in some terminal sense. But practicing enquiry too soon, and without a suitable background of knowledge, can have a narrowing and cramping effect on the individual's development of independent thinking. And if this is true at the level of the college sophomore, surely this danger must be all the more severe if we consider the instructional situation in the high school and the elementary school.

Is this a valid objection? If practice in enquiry can be given too soon, or too exclusively, what other parts are there to the instructional situation? What else is there to learn, if one does not practice the strategies of thinking?

TWO OTHER COMPONENTS OF INSTRUCTION

There are two other major capabilities which are of importance as objectives of instruction. It is possible to think that they are at least as important as practice in enquiry, and it is possible to argue that they are even more *essential*, in the sense that they represent *prior requirements*, if the practice of enquiry is to be carried out successfully. These two other capabilities may be characterized as follows:

(1) the capability of *generalizing* the principles of knowledge to the variety of situations to which they are applicable (and have been shown to be applicable by earlier scholars).

(2) the capability of *discriminating* the probable and improbable applicability of hypotheses to new problem situations.

In general terms, the reasons why these kinds of capability need to be fostered by the instructional situation are easy to understand. If an individual is to try to solve new problems, he must have a knowledge of a great variety of principles which can be potentially applicable to these problems. The best guarantee that these principles are available will be to insure that he has acquired generalizable knowledge, in other words, that he has *broad knowledge*. And when he does make the inductive leap that characterizes enquiry, he should be able to know that he is doing something that has a probability of being right, rather than of just being silly. He must discriminate the good ideas from the bad, in accordance with their probable consequences. One might call this *critical or incisive knowledge*. But both of these are needed *before* practice in enquiry can have the positive effects that are expected of it.

Generalizable Knowledge

Consider again the student who is asked to use the sliding of a weight down an inclined plane as an instance compatible with Newton's second law. It is obvious, isn't it, that the student must have a rather sizeable amount of broad knowledge before he can be successful at this problem? Among other things, he must know (1) what Newton's second law is, in terms which make sense to him; (2) what acceleration is, and its relation to velocity, time, and distance; (3) what mass is, and how it is related to weight; (4) how the angles of an inclined plane can lead to a conceptualization of the magnitude and direction of the forces at work. Others could undoubtedly be mentioned. It is senseless to think that these principles of knowledge are trivial, or that the student can easily have "picked them up" incidentally to some other learning, including perhaps previous practice in enquiry. It is surely wrong to believe that the student can *think* without *knowing* these principles. This would be like asking him to play chess without ever having learned what the rules are. And it is probably quite contrary to the interests of learning to ask the student to undertake "enquiry practice" without knowing these principles. As evidence for the latter statement I refer to some work of my own and my colleagues on learning in mathematics, which has shown clearly that learning to solve new problems is critically dependent upon the acquisition of previous knowledge.⁴

Broad, generalizable knowledge is a prerequisite for the successful practice of enquiry, whether as a part of the total instructional process or as a terminal capability. How does the student acquire this broad knowledge? Well, that is a question of great interest to a student of human learning. And some things are known about it, some things not yet. Here are some observations about this broad, generalizable knowledge that are relevant.

1. Such knowledge cannot all be attained by a student by the use of the method of enquiry itself. Were we to follow this suggestion, we should have to put the student back in the original situation that Newton found himself in, and ask the student to invent a solution, as Newton did. It would be difficult to achieve this situation, in the first place, and presumably not all students would achieve what Newton did, even then. But the major difficulty with this suggestion is that it would be a most terrible waste of time. Are we going to have students rediscover the laws of motion, the periodic table, the structure of the atom, the circulation of the blood, and all the other achievements of science simply in order to ensure that instructional conditions are "pure," in the sense that they demand enquiry? Surely no one seriously proposes that this method should be followed.

2. The possession of broad and generalizable knowledge is an admirable capability, and not to be equated with "knowing facts." There is quite a

difference between knowing a *fact*, such as "Newton invented the laws of motion," and a *principle*, such as might be exhibited if we asked a student to describe a situation which could be used to test Newton's second law of motion. One might call the ability to repeat verbally the statement, "If an unbalanced force acts upon a body, the body will accelerate in proportion to the magnitude, etc.," knowing a fact. But to know such a fact is not the same as knowing this law of motion as a principle, as the previous example has indicated. Knowledge of principles is generalizable; one expects a student who knows Newton's second law as a principle to be able to describe a wide variety of specific situations in which the validity of the law can be tested. Such knowledge is of tremendous value, not just in and of itself, but because it constitutes an essential basis for acquiring other knowledge. To an equal degree, it is an essential basis for the practice of the strategies of enquiry.

3. As to how knowledge is acquired, one should not assume that this has to be done, or is best accomplished, by "routine drill." Repetition does indeed appear to be one desirable condition for instruction, but only one. At least equally important, if not more so, is the condition which fosters the use of *discovery* on the part of the student. In its simplest form, this means simply that it seems to be better for learning if one can get the student to respond to a situation in his own way, and in a way which is also correct, rather than having him "copy" or "echo" something that the teacher says or the book says.^{2, 5} In other words, discovery appears to be a very fundamental principle of good instruction. It applies to *all* conceptual learning, the learning of principles and generalizations, and may even apply to the learning of a simpler sort such as the memorizing of names or facts. But discovery, as a very fundamental condition of most learning, should not be equated with enquiry, which is the exercise of all the various activities making up what we have identified as the terminal capability. The construction of a response by a learner, something that happens nearly every step of the way in the process of learning, is what usually has been called discovery. In contrast to this, enquiry is the terminal thinking process we want the student to be able to engage in, *after* he has taken all the necessary previous steps in learning.

In summary then, it appears that broad, generalizable knowledge is best conceived as knowledge of principles. As such, it may be attained in the context of instructional conditions which include "discovery" on the part of the learner. Knowledge of principles is not what is usually referred to in a deprecating manner as "knowledge of mere facts," nor is such knowledge best acquired under conditions of sheer repetition. But knowledge of principles is prerequisite to the successful practice of the techniques of enquiry.

Incisive Knowledge

The other kind of capability we have identified as prerequisite to

successful enquiry is the possession of critical or incisive knowledge. In terms that the psychologist uses, this is the capability of *discriminating* between a good idea and a bad one, or between a probably successful course of action and a probably unsuccessful one.

Just for variety of illustration, let us take a new example. Suppose we set the student this problem in enquiry: "How does the picture of an object get 'into the head' in the sense of being experienced as a picture and retained from one occasion to another?" Suppose that the student has a certain amount of generalizable knowledge about the eye, and its function as a camera, so that he is able readily to recall the principles which get the picture onto the retina. But now, how does it get "into the head"? If he has no more knowledge than this, he may think of a variety of mechanisms, each of which may be brilliantly inventive, but some of which may be silly. Perhaps it is carried by a scanning mechanism similar to television. Perhaps the frequencies of various light waves are transmitted directly over nerves. Perhaps the pattern of neurones stimulated corresponds to the pattern of physical energy. Perhaps the stimulation is carried in some mechanical way. Perhaps there are differences in the strength of electrical transmission. Perhaps the pattern of brightness is transmitted as a pattern of frequencies, different from those of the light waves themselves. And so on. Any fairly bright student can probably think of quite a large number of possibilities.

Is there an instructional value to encouraging students to make such guesses? Probably so, but *only when* the means are simultaneously provided for the student to estimate that an idea is probably good or probably bad. The wildness of the guesses, or perhaps even the frequency of wild guesses, is a most doubtful criterion. (People whose guesses are extremely wild are called schizophrenics.) It seems to me that if the student is encouraged to form hypotheses, even to follow hunches, as a part of practice in enquiry, that these hunches and guesses should be *disciplined* ones. This does not mean at all that hypotheses need to be restricted in scope or simple in content. On the contrary, they can be as elaborate as his abilities and his generalizable knowledge will permit. But he should be able to estimate their consequences. Any hypothesis is subject to the discipline of ultimate verification.

What kind of knowledge is it that makes possible the discrimination of good ideas from bad? Well, it is not very different in kind, although it is different in content, from the other kind of knowledge we have described. Generally speaking, it is knowledge of principles, sprinkled here and there, perhaps, with a few facts. In the case of our example of the picture in the head, the student needs to know at least the following principles: (1) the relation between intensity of stimulation and frequency of neural response; (2) the frequency and strength of neural responses; (3) the rapidity of the nervous impulse; (4) the relation between distribution of nerve endings and distribution of frequency of nervous impulses; and a

number of others. Each of these principles and facts provides him with a means of checking the compatibility of the hypotheses he generates in terms of their probability or improbability.

Here again, then, in this capability for *self-criticism of ideas*, we come upon another essential need for knowledge, prior to the exercise of enquiry. From a base of knowledge of principles, enquiry takes off. Where it comes to rest is also dependent upon the possession of knowledge. Enquiry which cannot be checked against estimates that hypotheses are probably good or probably bad will be undisciplined enquiry, possibly as exciting as the daydreams of Walter Mitty, but of no greater social importance. Likewise, the practice of enquiry which lacks the discipline of self-criticism may be expected to be of no positive value to the development of the individual, and could even be harmful. Which teacher of science has not encountered the student who is constantly willing to display a bubbling fountain of ideas, almost all of them worthless? Is this **what we want to encourage?**

THE INSTRUCTIONAL BASIS OF ENQUIRY

This analysis of the instructional conditions required to establish the capabilities for enquiry emphasizes that the major essential is the possession of a body of organized knowledge. On the whole, the more highly organized this knowledge is, the better, it will be better retained **that way.**

What are the implications of this line of reasoning for the science curriculum and for science instruction? It may be of greatest meaningfulness if the answer to this question is attempted by considering what science instruction might be like, not at some particular level of development, such as high school or college, but throughout the entire range of the educational sequence from kindergarten onwards. However, this might be better done "from the top down," because the interrelationships of problem-solving, knowledge, and fundamental skills are most clearly revealed by such an analysis. Accordingly, let us consider what seem to be approximately definable "levels" of science instruction. Of course these are not hard and fast distinctions, nor are they exclusive categories. Learning takes place during the entire course of an individual's lifetime, and it is only the relative priorities which can be indicated by **such an analysis.**

The Independent Investigator

At the highest level of development we have the student who is beginning to take all of the responsibilities of an independent scientist. He has broad knowledge, not only within his specialized field, but of others as well. Furthermore, he understands and has practiced the methods of enquiry sufficiently so that he knows what he is doing, and understands

his own limitations. He is able to begin a new line of investigation in a disciplined, responsible manner, with deliberate attention to what has gone before, but with a mind unhampered by tradition. Currently, we think of this capability as being possessed by the second- or third-year graduate student. If our educational system were reasonably effective, this level could perhaps be achieved by people of the age of present college juniors.

The Scientific Enquirer

At the next lower level, we find the student who has acquired enough broad subject-matter knowledge to be able to learn to speculate, to form and test hypotheses about scientific problems which are not trivial, and which he himself can subject to the discipline of self-criticism. In other words, the emphasis at this level of instruction might profitably be upon the method of enquiry. This should be practiced in the discussion class, in the laboratory, as well as in individual study. Again, making the assumption of a reasonably efficient educational system, the student should probably be able to begin this phase of instruction at the age of present 11th graders.

But in order to do this successfully, we have argued, he must have acquired a great deal of broad and incisive knowledge. The latter kinds of knowledge are not confined to the facts and principles of content, it should be noted. They also include knowledge about methods—of observing, classifying, describing, inferring, and conceptual invention.

The Student of Knowledge

This level of instruction emphasizes the learning of broad and critical knowledge, particularly of what previous generations of scientists have found out about the world, as well as the more fundamental principles which have led to the formulation of modern scientific conceptions. At this stage, the student needs to begin to acquire large masses of previously formulated principles of knowledge. At the same time, he needs to learn to engage deliberately and systematically in the fundamental activities used by the scientist, in as wide a variety of contexts as possible. Such activities include controlled observation, classification, measurement, inference, the formulation of models. Accordingly, there is definite need for the "laboratory" at this level. But the activities resemble those of the "laboratory exercise" more than they do the "independent enquiry." If he is encouraged to do the latter, he will fail because he doesn't *know* enough to behave like a scientist. Accordingly, his activity will either be extremely narrow in scope or will tend to be ridiculous, neither of which outcomes will have salutary effects upon his learning.

Does this suggestion of an emphasis on acquiring broad knowledge carry the implication of "stifling curiosity"? Not at all. There are plenty of

rewards for curiosity, in discovering new things about the world, in exploring previously unknown paths of knowledge, in trying one's hand at new kinds of classification, in finding out how indirect measurements can be made and verified, in seeing how one can best communicate scientific information, and in many other areas. Curiosity is not the special possession of the fully trained scientist. Neither is the method of discovery in learning, as has been pointed out previously.

This level of instruction could probably have its inception around the age level currently attending the 6th or 7th grade.

The Competent Performer

Acquiring broad knowledge in the way that it should be acquired, and particularly knowledge of the methods of the scientist, is in turn based upon a stage of instruction which extends downward to the kindergarten (and informally, farther than that). For what is needed first of all in science instruction are certain kinds of performance capabilities. The word *skills* should carry no negative aura, but it seems to for some people, so let us avoid it and refer to *competencies*. At this level, the question is not so much "Does the student *know* something," but "Can he *do* something." We are used to thinking of these competencies as "reading, writing, and arithmetic," but what an inadequate description that is! When one considers the competencies needed for learning about science, it is quite probable, first of all, that this set of three leaves some important ones out. Beyond this, they do not adequately convey what kinds of specific capabilities are really intended.

No one seems to have adequately faced up to the necessity for identifying and describing these fundamental competencies which underlie all of learning about science. A good list would include not only number computation, but also spatial and manipulative skills, and the capabilities of observing, classifying, measuring, describing, inferring, and model conceptualizing. In general, there should be good agreement that these competencies are important to science instruction. Shouldn't the high school student know how to *describe* an unfamiliar object seen for the first time? More than this, though, the suggestion made here is that the later acquisition of broad and incisive knowledge about science will be inadequate and unsuccessful unless the student has already acquired the capability of observing and describing what he sees. How can he acquire such knowledge unless he is able to distinguish clearly, and in terms of his own behavior, the description of an observed object or event from the description of a conceptual model?

As stated earlier, instruction in these fundamental capabilities so essential to the understanding of science carries no implication of the "routinizing of instruction" or the "deadening of curiosity." A child simply has to learn to read before he can understand printed texts. Similarly, an individual needs to know how to observe, to classify, to

describe, to conceptualize, before he can understand science or the activities of scientists. All of these competencies can be acquired through his own efforts, motivated by his own curiosity, and by means of his own discoveries.

At the same time, it seems to be totally erroneous to look upon these early attainments as having anything but a specious resemblance to the activities of disciplined enquiry, or to contend that they can be acquired by "practice in enquiry." One doesn't learn to be a scientist, or to appreciate science, by pretending to be a scientist. What is the difference, in principle, between trying to "practice enquiry" in the second grade, and trying to practice "being a physician" at the same age level? Why should anyone be led, perhaps by wishful thinking, to give serious consideration to the former, while at the same time chuckling patronizingly at the latter? Engaging in enquiry of a successful, productive, and useful variety can be undertaken when the individual has acquired a store of broad and critical knowledge, and this in turn can be acquired when he has learned some prerequisite but very important fundamental capabilities. At the earliest stage of instruction, one needs to be most concerned with these latter competencies, which will remain with the student all his life.

Having described a sequence of acquired competencies from top to bottom which is based upon the best generalizations from studies of the learning process, one must be careful not to imply that there is no overlap among the kinds of capabilities to be acquired at each of these four "levels" of instruction. At the earliest stage, for example, the child is certainly acquiring some knowledge of principles, and even a little bit of the strategy of clear thinking, even though the major part of what he most needs to learn are the competencies (or skills) mentioned. And similar comments could be made about other stages. None of them is "pure." Even at the highest of these levels, as we know, the student may often have to "catch up" on some broad knowledge he somehow missed at a much earlier level. If he has missed some of the important competencies at the earliest level, the chances are very good that he has some time previously decided to major in some field other than science.

In summary then, let us consider what would happen in science instruction, this time beginning at the bottom, if it were seriously designed to establish the terminal capability of enquiry. This is not an attempt to describe what *does* happen, because we are far from that condition, but what *should* happen. At the earliest level of instruction, the individual needs to learn how to observe, how to figure, how to measure, how to orient things in space, how to describe, how to classify objects and events, how to infer, and how to make conceptual models. These capabilities he will use all of his life. If he becomes a student of science, they will make possible the acquiring of broad knowledge of principles, the incisive knowledge which makes possible the self-criticism of new

ideas, and the disciplined exercise of the method of enquiry. If he chooses some other field as a career, they will provide a fundamental understanding of science which is quite independent of any particular scientific knowledge he may read about. At the next level, he needs to make a thoroughgoing start at acquiring broad knowledge and critical knowledge of the principles of science, throughout the various disciplines, and including knowledge of both content and method. This knowledge is essential if he is later going to practice making reasonable hypotheses and testing them; in other words, if he is later to practice enquiry. The practice of enquiry itself might begin at the next stage, along with a continuation of the learning of substantive knowledge, perhaps with a somewhat greater degree of specialization. This enquiry practice will, on the one hand, be soundly derived from suitably broad knowledge, and on the other, it will be carried out so as to make possible discriminations between "good" and "bad" ideas. But it will nevertheless be genuine enquiry, in which the student is encouraged to solve problems by means of unrestrained inductive thinking, and in which he is rewarded for his ingenuity. Having done all this, the student is then ready for the final stage, learning to assume the full responsibilities of the scientific investigator. At this stage, he must learn to depend upon himself, and to trust himself, to look upon problems objectively, to have new ideas, and to be able to judge them critically. In all of these activities he will be enormously aided by his previous practice in enquiry, as well as by his knowledge of scientific principles and methods, and by the fundamental capabilities he acquired early in his educational career.

It must be quite clear that "practice in enquiry" for the student of science has great value. But to be successful it must be based upon a great variety of prerequisite knowledges and competencies which themselves are learned, sometimes by "discovery," but inconceivably by what is called "enquiry."

References

- 1 Schwab, J. J., "The Teaching of Science as Enquiry," *The Teaching of Science*, Harvard University Press, Cambridge, 1962.
- 2 Bruner, J. S., "The Act of Discovery," *Harvard Educational Review*, 31, 21-32 (1961).
- 3 Yang, C. N., quoted in article in *Pittsburgh Post-Gazette*, Friday, December 28, 1962.
- 4 Gagné, R. M., J. R. Mayor, H. L. Garstens, and N. F. Paradise, "Factors in Acquiring Knowledge of a Mathematical Task," *Psychol. Monographs*, 76, No. 7 (Whole No. 526) (1962).
- 5 Gagné, R. M., "The Acquisition of Knowledge," *Psychol. Rev.* 69, 355-365 (1962).

STATEMENT OF PURPOSES AND OBJECTIVES OF SCIENCE EDUCATION IN THE ELEMENTARY SCHOOL*

William Kessen

William Kessen defines science as a structured and directed way of asking and answering questions. He believes science is best taught as procedure of enquiry. Dr. Kessen believes that the objectives in science education should include an attitude of intelligent caution and such procedures of science as the ability to state a problem, use sources of reliable information, observe, compare, classify, measure, experiment, evaluate evidence, draw conclusions, invent a model or theory, and communicate in science. Dr. Kessen also sketches an outline of the basic areas of scientific knowledge that a properly educated child should possess within the first ten years of school.

There is joy in the search for knowledge; there is excitement in seeing, however partially, into the workings of the physical and biological world; there is intellectual power to be gained in learning the scientist's approach to the solution of human problems. The first task and central purpose of science education is to awaken in the child, whether or not he will become a professional scientist, a sense of the joy, the excitement, and the intellectual power of science. Education in science, like education in letters and the arts, will enlarge the child's appreciation of his world; it will also lead him to a better understanding of the range and limits of man's control over nature.

SCIENCE AS INQUIRY

Science is best taught as a procedure of enquiry. Just as reading is a fundamental instrument for exploring whatever may be written, so science is a fundamental instrument for exploring whatever may be tested by observation and experiment. Science is more than a body of facts, a collection of principles, and a set of machines for measurement; it is a

* REPRINTED FROM *Journal of Research in Science Teaching*, Vol. 2, Issue 1, 1964, pp. 4-6, by permission of the author and the editor. Dr. Kessen is Professor of Psychology at Yale University.

structured and directed way of asking and answering questions. It is no mean pedagogical feat to teach a child the facts of science and technology, it is a pedagogical triumph to teach him these facts in their relation to the procedures of scientific enquiry. And the intellectual gain is far greater than the child's ability to conduct a chemical experiment or to discover some of the characteristics of static electricity. The procedures of scientific enquiry, learned not as a canon of rules but as ways of finding answers, can be applied without limit. The well-taught child will approach human behavior and social structure and the claims of authority with the same spirit of alert skepticism that he adopts toward scientific theories. It is here that the future citizen who will not become a scientist will learn that science is not memory or magic but rather a disciplined form of human curiosity.

THE SCIENTIFIC ATTITUDE

The willingness to wait for a conclusive answer—the skepticism that requires intellectual restraint and the maintenance of doubt—is oftentimes difficult for adult and child alike. The discipline of scientific enquiry demands respect for the work of the past together with a willingness to question the claims of authority. The attitude of intelligent caution, the restraint of commitment, the belief that difficult problems are always susceptible to scientific analysis, and the courage to maintain doubt will be learned best by the child who is given an honest opportunity to try his hand at scientific enquiry. With his successes will come an optimistic appreciation of the strength of enquiry, with his failures will come an understanding of the variety and challenge of our ignorance. For the scientist, child and adult, novelty is permanent, scientific enquiry continually builds novelty into a coherent design, full of promise, always tentative, that tames our terror and satisfies for a while the human desire for simplicity.

THE PROCEDURES OF SCIENCE

Scientific problems arise in the play of children just as they arise in the guided exploration of scientists. Astonishment in the presence of natural beauty, surprise—even frustration—at the failure of a prediction, and the demand for sense in the face of confusion are the beginnings of scientific enquiry. **But how do we then proceed?**

Among the most demanding of scientific tasks and certainly among the most difficult to teach is the *statement* of a problem. Is there a meaningful question to be asked? What techniques should be used to answer it? How does one go about making a prediction or developing a hypothesis? As he asks these questions, the student begins to learn how active enquiry can lead to testable questions and eventually to the

solution of problems. He is introduced also to the pleasures and problems of inventive thought—of considering what might be as well as what is.

There are many ways to answer a provocative question in science and the child should come to recognize that he must adapt his method to the problem in hand. As he runs against different problems, the child will learn to use several *sources of reliable information*—observation, experiment, books, museums, and informed adults.

Whatever the problem, the child's *ability to observe* should be extended so that he understands the wide range of observations possible even when simple phenomena are under study. He must learn to order the evidence of all his senses.

Attention to the complex activity of *comparison of phenomena* will introduce the child to an essential task in science—the perception of differences and similarities among events.

The child will use his ability to observe and to compare in building *systems of classification* and in recognizing their usefulness and their limitations in science.

The child should learn to use the *instruments of science*. As he studies these instruments, the teacher is given an opportunity to instruct the child in *measurement*. He will learn the need for precision in measurement, the importance of agreement among observers, and the relations among different systems of measurement.

The use of laboratory techniques—especially *the experiment*—deserves special attention. The experiment is the sharpest tool of science and in devising an experiment, the child exercises his ability to pose a question, to consider possible answers, to select appropriate instruments, to make careful measurements, and to be aware of sources of error. It is unlikely that children in the first years of school will manage well all aspects of sound laboratory procedure but the best lessons of the experiment can be taught only to the child who is actively engaged with the equipment and procedures of the laboratory. The teacher must adapt his desire for precision to the child's excitement in the search; a premature demand for exactness in experimental manipulation may blunt the student's commitment and pleasure.

After the problem is posed, a hypothesis developed, and the data gathered, the science student must *evaluate evidence and draw conclusions*. Sometimes this is a simple step; sometimes it involves the review and modification of the entire plan with renewed attention to problem, to hypothesis, and to data-protocols. The goal is to make sense of the data and the pursuit of this goal will on occasion lead to the detection of an error or to the design of another study. It may also lead to the *invention of a model or theory* through which we can comprehend data.

Throughout the course of science education, the *need to communicate* is present. Describing a bird to his class, graphing a mathematical function, writing an experimental paper—experience with each mode of report is essential to the development of the science student.

The child's ability to communicate in science will both depend upon and contribute to the achievement of this most general goal of the curriculum—accurate and effective communication.

The procedures of science described here in the context of early science education are recognizably the procedures of science at all levels of sophistication. Scientific enquiry is a seamless fabric. The content will change, the demand for precision will vary, the generality of conclusion will be different, the interrelation of studies will be understood in different ways, but the procedures and attitudes of scientific study remain remarkably the same from the time the kindergarten child wonders about color to the time the graduate physicist wonders about particle emission.

SCIENTIFIC KNOWLEDGE

The facts and principles of science change with each advance in our understanding of the world. For this reason, it is difficult to forecast with precision what scientific content the child should know. Nonetheless, it is possible to sketch in outline the scientific knowledge that the properly educated child will possess within the first ten years of school. A knowledge of the basic findings of centuries of scientific enquiry gives boundaries and direction to the child's active exploration of his world. Under the governing premise that the curriculum in science must be defined by the child's growing comprehension of nature's order and beauty more than by the conventional categories of scientific knowledge, the child should know as much as he can actively seize about

1. *the universe*, its galaxies, our solar system, the earth, and his immediate environment; the range of measurements used to describe astronomical and geological phenomena;

2. *the structure and reactions of matter* from the smallest particles to their combination in minerals and rocks; elements, compounds and mixtures, large and small molecules, atoms, protons, neutrons, and electrons;

3. *the conservation and transformation of energy*, the electro-magnetic spectrum, energy of motion and potential energy, electrical energy and chemical energy; force and work, gravitational and magnetic fields,

4. *the interaction between living things and their environment*, animal and human behavior, the relation between biological structure and function, reproduction, development, genetics, evolution, and the biological units—cell, organism, and population.

Science cannot be divided easily into labeled categories without loss. An emphasis on *scientific principles* that bridge the conventional subject-matter divisions will improve and simplify the teaching of science, making it more easily understood and more productive of meaningful problems for the child's own enquiry.

Scientific enquiry, moreover, is partner and peer of the traditional divisions of study; decisions about education in science must always be made with consideration of the relation of science to the child's other

studies. Levers and poems, energy exchange and historical analysis, genetics and geography—all present to the child an opportunity to extend his reach into the world and, in their different ways, all present to the child an opportunity to see beauty.

THE CHILD AND THE TEACHER

Rising above any statement of objectives for education is an irreducible fact. Teaching is an exchange between people. This simple human fact is both problem and promise for education in science as it is for all education. The child can understand only what he has been prepared to understand, the teacher can teach only what he knows, and the meeting of the prepared child with skillful teacher is an unforgettable encounter for them both. In the successful educational encounter, the child will become an active searcher for knowledge and the teacher will form attitudes toward enquiry as well as offer information about the world. The related and intricate problems of teacher training and the nature of learning are closely intertwined with the goals of science education. Science, rooted in man's curiosity and love of order, is called to its full humanity by the child's desire to know.

SCIENCE TEACHING IN THE ELEMENTARY SCHOOL*

Paul E. Blackwood

Paul E. Blackwood presents his definition of science as "man's relentless search for verifiable patterns, concepts, descriptions, or explanations of phenomena in the universe." The recorded knowledge that results from this search, and about which people communicate, is an important part of science. Dr. Blackwood briefly discusses three basic things that scientists do: they make descriptions, explanations, and predictions. He uses a three-sided polygon to describe the necessary components of a good science education program. Side 1 represents objects, forces, and phenomena that make up the universe. Side 2 represents methods of

* REPRINTED FROM *Science and Children*, Vol. 2, No. 1, September 1964, pp. 21-25. Copyright 1964, by the National Science Teachers Association, Washington, D.C. Reprinted by permission of the author and the publisher. Dr. Blackwood is Specialist for Elementary Science at the U.S. Office of Education.

inquiry used to study the universe. Side 3 represents the knowledge (classified as concepts, principles, laws, facts, etc.) developed about the universe.

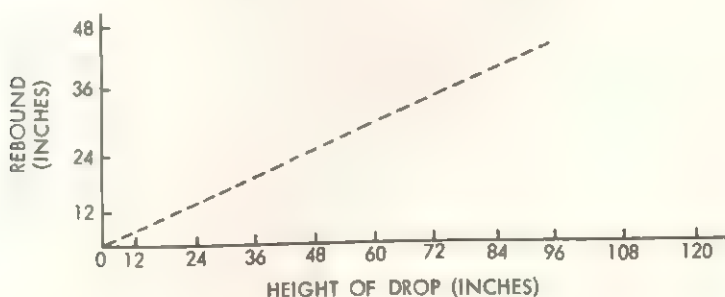
What you see and hear in the corridor of an elementary school is often related to what goes on in classrooms. This visitor was lured into a fifth-grade classroom by a girl energetically bouncing a red rubber ball.

Inside the classroom other pupils were dropping rubber balls. They were investigating how high a ball would bounce when dropped freely from various heights. After a short period of activity, the children and teacher were confronted with 15 sets of data collected independently by 15 two-man teams. What one team recorded is shown in Chart 1.

CHART 1

<i>Height of Drop (Inches)</i>	<i>Trial</i>	<i>Rebound (Inches)</i>
24" (2')	1	11.00"
	2	11.50"
	3	11.75"
	Average	11.41"
48" (4')	1	22.50"
	2	22.75"
	3	23.25"
	Average	22.83"
72" (6')	1	33.00"
	2	33.75"
	3	34.00"
	Average	33.58"
96" (8')		?
120" (10')		?

How would these results look on a graph? The question by the teacher was sufficient motivation to cause the team to prepare a graph of the results similar to the one below.



Additional questions began to emerge:

1. How far would the ball bounce if dropped from 8, 10, or 12 feet?
2. By using the graph, can one predict the height of rebound?
3. Is there a maximum height the ball will bounce, regardless of the distance it falls?
4. How does the bounce of different balls compare?
5. Do heavier balls bounce higher than lighter balls?

In another class, children were discussing the question, "How does the length of a stick's shadow change as the sun moves across the sky?" First, the children changed the question into a form which could be investigated more directly. They worded it this way: "What is the length of a stick's shadow at different times of the day?" An answer to this question could be obtained by direct measurement, and data collected to answer it would help answer the first question, so the class decided. It was not long before 15 pairs of pupils were busy in the schoolyard collecting information. Each pair was confronted with certain questions:

How long a pole shall we use?

Where shall we place it?

At what intervals during the day shall we measure the shadow?

Two children decided to measure the length of the shadow of an 88-inch pole every hour from 8 AM to 3 PM, just south of the school house. They measured it on June 7 and again on June 10 because the sun disappeared just after noon on the 7th. Their recorded data are illustrated in Chart 2

CHART 2

Length of Pole: 88" (7'4")
Position: South of School House

Time	Length	
	June 7	June 10
8 AM	122" 10'2"	
9 AM	81" (6'9")	
10 AM	54" (4'6")	
11 AM	37" (3'1")	
12 M	28" (2'4")	
1 PM	Cloudy	36" (3')
2 PM	Cloudy	53" (4'5")
3 PM	Cloudy	79" (6'7")

Based on these figures, the children were able to answer their questions about the changing length of shadows in relation to the position of the sun. But one youngster asked, "Does this experiment prove that the earth rotates or that the sun moves?"

The two learning experiences described above may well illustrate some characteristics of good science teaching. But a judgment can be made only in terms of what one accepts as a model of science education. Before evaluating these, or any science experiences, let us consider a model of science education which clearly recognizes two essential and perhaps interrelated features.

1. The nature of science.
2. The purposes and methods of teaching science.

Surely a growing understanding of each of these by teachers of elementary school science is essential.

1. The Nature of Science

A working definition of science is helpful in giving clues as to what may properly be included in the study of science. The following tentative definition has the virtue of including enough ingredients to reflect the breadth and richness of science. *Science is man's relentless search for verifiable patterns, concepts, descriptions, or explanations of phenomena in the universe.*

In this definition, we see that man is in the picture. Science is an enterprise, an activity of people. Science is people searching. It is men, women, and children investigating, inquiring, and seeking verifiable knowledge. It is relentless, a continuous, never-ending attempt to find more accurate descriptions of things and events and to seek reasonable explanations of these events. The search leads to new discoveries, to new insights about unifying patterns, to concepts, to understandings, and to new knowledge. Many of these observations, descriptions, and explanations have been recorded by scientists and are available for use by other people as they attempt to extend their knowledge and understanding of the natural environment. This recorded knowledge, about which people can communicate, is an important part of science.

A definition of science like that discussed above has been eschewed by some scientists on the grounds that you can define science better in terms of what scientists do. It seems simple to say, "Science is what scientists do." But to understand this statement requires an analysis of what it is that men and women do when they are being scientists. Let us then, in our exploration of what science is, look briefly at three of the basic things that scientists do.

A. SCIENTISTS MAKE DESCRIPTIONS. What is in the universe? How many? How much? How long? How frequently? Where? When? Under what circumstances? Answers to such questions are descriptions.

Astronomers use telescopes, cameras, and instruments of other kinds. They use mathematics and their minds to try to get a picture of our universe and how the bodies in space are interrelated. Geologists study rock structures, formations of the earth, and changes in its surface. The study requires careful observation and accurate reporting. Physicists attempt to find out how energy flows from one material to another and what happens to the materials.

Thus, scientists attempt to describe what is, how things are, what things are like, how they change, and how they interrelate. Improved descriptions of things and events in our universe enable scientists to discover unity within vast diversity. Methods that have proven practical in discovering the elements of unity within diversity and in getting "check-up-able" knowledge we sometimes call scientific methods. As other people use these methods, they are able to verify what someone else has observed.

B. SCIENTISTS MAKE EXPLANATIONS. In a sense, scientists attempt to tell "why" certain events and phenomena occur the way they do. This usually involves observing carefully how things interact with each other. What are the interrelationships? What precedes what? What follows what? Under what conditions do certain phenomena occur? Making explanations usually involves showing the connections between events or phenomena.

In a way, an explanation is a very careful description. For example, to explain why water evaporates from an open dish requires knowledge about the physical structure of water, about the nature of molecular action, about the capacity of air to hold water molecules, the behavior of water molecules when heat energy is increased, and the like. Scientists are detectives attempting to put descriptions together in ways that help us understand events. In this way, they make explanations.

C. SCIENTISTS MAKE PREDICTIONS. In order to make knowledge more widely applicable and to extend our confidence in its validity, it must be tested in many situations. Extending our knowledge to new situations involves prediction. We have observed that water will evaporate from a dish on a window sill. We predict that it will evaporate also if placed on a warm radiator. We test to see. If it does, then our prediction is correct.

Scientists are continually testing to see if principles that apply in one situation will apply in another. Making use of a concept of generalizations or law in a situation which has not yet been tested involves prediction. Scientists have not been on the moon. Yet numerous predictions of what it is like there have been made and may be proven true. Actually, the

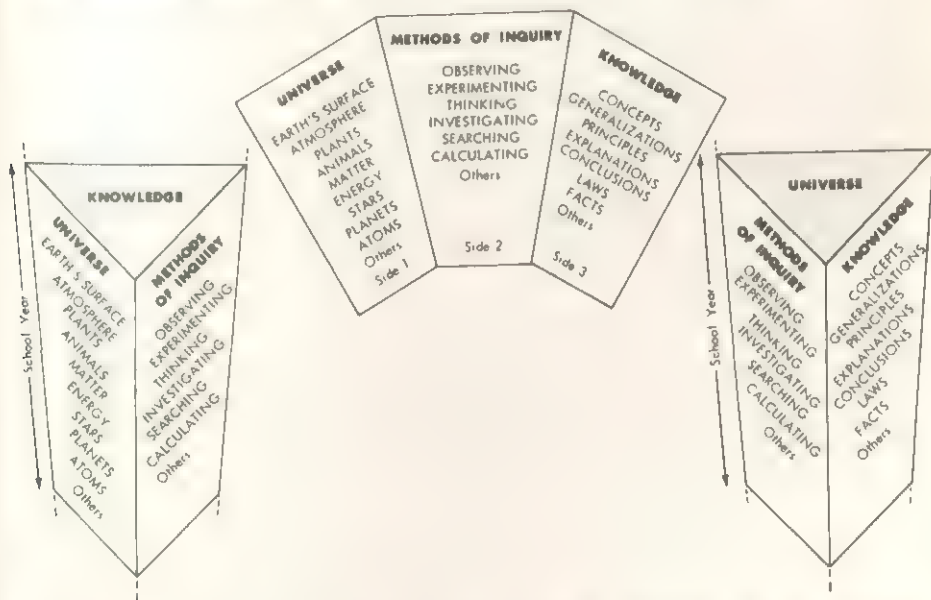
acceptance of certain predictions as fact enables planning for the moon launch to proceed with confidence. Making predictions is an important part of what scientists do.

In making descriptions, explanations, and predictions, scientists use their minds; they use ideas of their own and ideas of others as tools for testing and gaining knowledge. They use many resources to get valid answers to their questions or solutions to their problems. They may invent new tools with which to observe or to check phenomena more accurately. Thus, scientists do many things in relation to making valid descriptions, explanations, and predictions.

Now, having considered briefly the meaning of science and what scientists do, it is appropriate to ask whether good science teaching should make provisions for children to experience science in the sense discussed. Let us postpone consideration of this question while we examine the second feature of our science education model.

2. The Purposes and Methods of Science Teaching

One way of representing a science education program is shown in the accompanying figures. It provides us with a way of describing a science education program and of questioning and constructively criticizing our efforts. In Figure 1, we see a three-sided polygon tapering off toward the bottom and flaring out at the top.¹ If this three-sided figure is opened to show its three faces, it would appear as in Figure 2.



¹ Adapted from an unpublished working paper produced at the American Association for the Advancement of Science Conference on Science Programs for the Elementary and Junior High School, Cornell University, Ithaca, New York. 1962.

Side 1 represents our universe which is the subject matter of our study in the natural sciences. It includes objects and forces and phenomena. However, the universe and things in it are *not* science. They are simply objects and forces and phenomena. These things can be grouped and organized in various ways for purposes of study.

When we begin to study, to investigate, and to inquire into things in the universe, then science appears. Side 2 of the model represents some of the ways people go about investigating their world.

As a result of investigating the universe, people develop knowledge about it. Some of this is scientific knowledge which we may classify as concepts, principles, laws, and facts, for example. This knowledge is represented by Side 3 of the figure.

With this model before us for purposes of discussion (no model can *be* a science curriculum) we can visualize and think about the minimum requirements of a science program in the elementary school. Most important, the model suggests that our program must thoughtfully embrace a total concept of what science is. It is a study of the universe by methods that yield valid and reproducible knowledge. Reference to our model suggests a number of more specific considerations.

a. The universe is all around but how it is organized for study and what topics, questions, or areas are selected at a particular time is a matter of choice. Since everything cannot be studied at once, choices do have to be made. Though our model does not tell us this, it seems reasonable to believe that a variety of different choices may help children equally well to gain an adequate understanding of basic laws, principles, and concepts. For example, curriculums in some schools may focus on developing the concept of *variety* through study of "plants" and "rock forms" while another school system may organize such learning around "astronomical bodies" and "animals." To help children develop an understanding of the concept of *interaction*, some schools may organize learnings around "forms of energy" and "plant growth" while another may use "atmosphere" and "geologic changes" for this purpose.

CONCEPT DEVELOPMENT

b. The scientific knowledge which children learn may appear in different forms—as generalizations, principles, facts, conclusions, laws. Year by year children develop a more comprehensive set of concepts which they use as intellectual tools in interpreting and understanding new phenomena or problems. Keeping the focus on concept development enables curriculum planners and the teacher, in particular, to make judicious selection of the aspects of the environment to study so that there is not a compulsion to try to "cover" all aspects of our universe each year, or indeed year after year.

c. Helping children grow from less mature to more mature "practitioners" of the methods of inquiry is an inherent part of science teaching.

It is at this point that the temptation is great to insist that children should continuously have experiences doing the kinds of things scientists do.² If we recognize that children are not studying science primarily to become scientists and that science teachers may use a variety of methods and materials not necessarily used by scientists, then it seems safe to say that in good science teaching children should make inquiries and investigations, should make descriptions and explanations, and should make predictions. It might follow that teaching which denies children a variety of opportunities to "be like scientists" is neither science nor science teaching.

In this way of thinking about science teaching, the teacher has day-to-day responsibility for involving children in behaviors that are characteristic of scientists at work. Side 2 of Figure 2 shows some of the behaviors or activities of scientists. Lest the kinds of behaviors we refer to seem few, remote, and unidentifiable, we report here a longer list³ of clue words that suggest how rich is the array of possibilities.

d. The science curriculum must enable children at every level to build on their present experience and knowledge of science, always deepening and broadening their skills of inquiry and their understanding of concepts. The experience of each child must grow and expand as he explores new areas of the environment and deepens knowledge in old ones.

ATTITUDES AND OBJECTIVES

Let us return to our polygon again and view it from another side. (Figure 3) Other implications for a good science program can be deduced from the model. Perhaps the reader will attempt to enumerate additional implications. Do you see a place for considering attitudes and predispositions about science? Do you see implications for statements of objectives and purposes for teaching science?

Does the model serve as a guide for evaluating specific science activities? Let us try it on the activities described earlier—the children bouncing the rubber ball and measuring shadows—and begin to make a judgment about their potential value. Answers to questions such as the following are pertinent:

1. Did the activity involve the children in describing or explaining some phenomenon?

² An opposite point of view is developed by Derek de S. Price in an article, "Two Cultures and One Historian of Science." *Teachers College Record*, Columbia University, April 1963, pp. 527-535.

³ Based on an unpublished committee report of The American Association for the Advancement of Science Conference on Science for the Elementary and Junior High School, Cornell University, Ithaca, New York. 1962.

CLUE WORDS

Knowing

Observes
Identifies

Describes
Gathers

Accumulates
Counts

Looks
Sees

Manipulating

Measures
Balances

Selects
instruments

Computes
Demonstrates

Weighs

Applying

Classifies
Assigns
Defines
Associates
Arranges

Distinguishes
Organizes
Estimates
Equals
Sorts

Plans
Compares
Concludes
Experiments
Controls

Ponders
Groups
Decides

Creating

Hypothesizes
Induces
Deduces
Speculates
Analyzes
Selects data
Designs
experiments

Reflects
Proposes
Criticizes
Conceives
Invents
Guesses
Comprehends
Doubts

Incubates
Predicts
Estimates
Explains
Appreciates
Infers
Abstracts
Synthesizes

Formulates
Interrelates
Generalizes
Forecasts
Extrapolates
Interpolates

Evaluating

Ponders
Rejects
Accepts
Believes
Disbelieves

Pools data
Recognizes
errors
Equates
Distinguishes
Questions

Doubts
Verifies
Decides
Interprets
Criticizes

Transposes
Generalizes
Controls
variables

Communicating

Tabulates
Graphs
Writes
Speaks
Reports

Explains
Teaches
Informs
Charts
Reads

Debates
Argues
Describes
Demonstrates
Compares

Questions
Instructs
Plots
Draws

2. Did the children collect original data from which to draw conclusions?
3. Did the children organize and communicate about the data in useful ways?
4. Did the children have opportunities to speculate and predict?
5. Did the experience relate clearly to development of a major science concept?
6. Were some questions raised that provided stimulation for further study?

If the answer to most of these questions is yes, it is probable the science experiences in question are making a positive contribution to the science education of the children engaged in it.

This article has attempted to suggest that an understanding by teachers of what science is, particularly in terms of knowing what scientists do, is essential in developing the science curriculum or course of study. A rich science program involves children in activities that encompass the entire spectrum of ways of investigating the environment used by scientists. The effective science curriculum is planned so that children's learning activities are focused on gaining understandings of selected concepts as intellectual tools for dealing with new problems. At every level of school, children's insights and understanding of science concepts and methods should be deepened and broadened if the science program is to make its fullest contribution to the education of children.

RESEARCH AND DEVELOPMENT OF SCIENCE PROGRAMS: DIMENSIONS FOR CONSIDERATION*

Lawrence F. Lowery and Jerry S. Carlson

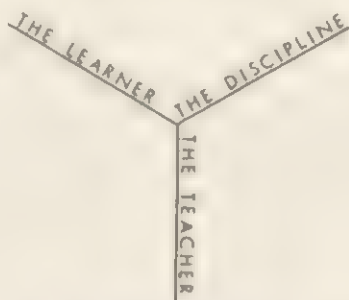
Dr. Lowery and Dr. Carlson set forth the central question which science educators must ask: "What tangibles should serve as guides for future practical applications in early childhood science programs?" The authors turn to three areas of scholarly endeavor which might serve as useful guidelines: (1) the research findings of child development, (2) the

* REPRINTED FROM *School Science and Mathematics*, Vol. 68, No. 6, June 1968, pp. 554-564. Reprinted by permission of the authors and the publisher. Dr. Lowery is Assistant Professor of Education at the University of California, Dr. Carlson is Assistant Professor of Education at the University of California, Riverside.

organized ways of knowing and learning within the science discipline, and (3) recent developments in research on the teacher and instruction. The authors believe that these three areas could help produce a theoretical and research framework for a needed new era in early childhood science education.

Today we realize more than ever the significance of early childhood education. Unfortunately our interest, though keen, has produced only a few programs in science education which are both soundly constructed and designed for the young child. Although the academic marketplace is now being besieged by commercial firms, and "packaged" programs are becoming popular items of educational hardware, the desired qualitative development has not taken place. The central question which we, as science educators, must ask is "What tangibles should, indeed could, serve as guides for future practical applications in early childhood science programs?"

To find useful guidelines, one might turn to several areas of scholarly endeavor. Three particular areas come first to mind. They are (1) the research findings on the many horizons of child development; (2) the organized ways of knowing and learning within the science disciplines themselves, and (3) the recent developments in research on the teacher and instruction.



These three areas, if carefully explored, examined, and properly understood, could help produce a theoretical and research framework for a needed new era in early childhood science education.

THE LEARNER

The vast quantity of research in this area prohibits an inclusive review of the literature. Instead, only a few strands of significant research and theory can be discussed and analyzed. Such a discussion can, then, only set the stage for further thinking and work, but it may serve as a necessary starting point for rethinking elementary school science education.

The work of Jean Piaget and his associates in Geneva has aroused interest in developmental psychology and in the thinking processes of the young child. Though Piaget's methodological approach, clinical findings, and theoretical formulations are open to criticism, they can serve as a starting point for consideration of children's thinking and cognitive development.

Piaget views intelligence as the individual's ability to act in certain ways and perform certain logical mental operations. Intelligence is a form of adaptive behavior which allows the individual to cope more effectively with his environment by organizing and reorganizing basic units of thought and action. The child, then, takes in and processes new information in the context of past experience which has, by-in-large, control over his existing mental structures or, in Piagetian language, schema.

For Piaget, cognitive development occurs in substages, stages, and periods, with each subordinate subdivision forming the basis upon which supraordinate stages and periods and periods can be built. The "mental structures" or "organizations" that exist at any time are constantly being modified by impinging environmental stimuli, and the growth of intelligence is a dynamic process which actively develops. Briefly, Piaget's approach has resulted in the construction of an image of cognitive development. This image suggests that cognitive development takes place sequentially in distinctive, yet overlapping and interdependent stages. The ages posited by Piaget are approximations and subject to variance from one child to another. The stages are, however, sequential and, as a child develops he must necessarily move in a unitary direction with the process reflecting a consistent order and with more mature behavior having its roots in the earlier stages. Full maturity is the final and total integration of all preceding stages.

The following, though brief and condensed, summarizes Piaget's taxonomy of developmental stages of the growth of intelligence. It is, perhaps, science education's best guideline to date.

Period I: The Period of Sensory-motor Intelligence (0-2 years of age)

In this period the child's organization is physical rather than symbolic. He adapts to his environment via sensory-motor means. Within this period Piaget posits six stages of development, with substages within these.

Period II: The Period of Concrete Intelligence (2-11 years of age)

This period, significant at the elementary school level, encompasses three important stages plus numerous substages.

The *preconceptual stage* (ages 2-4) occurs when the child attempts to regard objects in a symbolic sense. Symbolic representation and language development form the basis of this stage.

The *stage of intuitive thinking* (ages 4-7) is marked by the rudimentary development of logical thought. Objects can now be grouped into classes according to the child's perceptions of similarity and dissimilarity. The child now can act on the verbal

instructions of others as well as his own covert speech. He is still, however, perception bound and cannot separate cause from effect.

The *stage of concrete operations* (ages 7-11) is marked by the child's ability to be logically consistent and to conserve. In the earlier substages the child can conserve in some, but not all, instances. However, by the time the child has reached the last substage, the "principle of invariance" is firmly entrenched. One must note, however, that the child can apply the "principle of invariance" only to concrete situations. He is unable to deal logically in the symbolic abstractions of language.

Period III. The Period of Formal Operation (11-15 years of age).

At this level the child can "operate with operations" and engage in such cognitive activity as hypothesis generation and testing at a purely symbolic level. In short, the child has the cognitive tools for inductive and deductive reasoning, and can think as adults do when they operate abstractly.

The question "What does all this mean for early childhood science education?" is a real one and deserves our attention. Some research designed to test out and extend Piaget's work may serve as guidelines which can direct our thinking and help us understand the cognitive processes and development of the young child. It must be noted, however, that although a great deal of work has been done in the area of young children's thinking, many basic questions still remain as we are still searching for definitive answers to basic and complex questions. But, let us begin.

Research designed to test out the stage-wise development, as posited by Piaget, has generally supported his views. Interestingly enough, though the stages may differ slightly with respect to the ages Piaget suggested, the general sequence has found support regardless of the cultural background of the children. This fact, though certainly important, is not sufficient, as it is more descriptive than explanatory and does not really aid our understanding of the hows and whys of cognitive growth and development. The seminal question of "How does a child at various stages of cognitive development learn?" is vexing and not thoroughly understood. But, we do have some leads worthy of consideration.

1. *CONCEPT ATTAINMENT.* Piaget stresses the importance of the child's direct activity vis-a-vis the content. To Piaget, the development of thought (ergo, logical operations) is not due to the "stockpiling of information" or "insight" but based on the child's own activity. Thus, he views conceptual development as essentially the development of the schemata of action in which perception only plays a part.

The Geneva School, though not primarily interested in didactic technique or trition, does definitely place major emphasis on direct activity on the part of the child. It is felt that from direct and manipulative experience, logical inconsistencies would result in cognitive reorganization and development if the child had already formed the prerequisite systems of mental operations. Consequently the effects of external reward on the acquisition of behavior are not particularly

important, as dissonance reduction, due to the development of logically appropriate cognitive structures, serving as an internal reward.

While Piaget (1926) stresses activity and manipulation of objects, he minimizes the importance of language as a variable of functional importance for cognitive development and concept attainment. In other words, Piaget seems to separate thoughts from words as, for him, concepts are formed from action and language can then "make use of them."

Recent work (Carlson, 1967) has shown that basic cognitive structures are subject to the effects of tuition and the efficacy of the verbal mediation model is upheld. However, this work was done with seven year old children and perhaps younger children are not capable, or at least as capable, of verbal mediation as older children. The work of T. Kendler (1960) did show that improvement of reversal shift learning (increase use of verbal mediation) did take place for children whose ages ran from three to ten years. The percentage increased gradually to 62 per cent by age ten. Also, the percentage of children who responded inconsistently, decreased from 50 per cent for three year olds to 10 per cent for ten year olds. Subsequently, Kendler formulated the hypothesis that if relevant mediation were supplied, age differences would diminish or disappear. The Kendlers (1961), using four and seven year olds, found that those children who verbalized relevant information did significantly better than those who verbalized irrelevant information. The younger children (age four) did not, however, generally do as well as the seven year olds. They concluded that younger children are less responsive to their own verbalization than older children.

What are we to make of this? First, it would appear that all mediation is not verbal and, in fact, a postural or gestural mediation may precede and then lay the basis for later verbal control. At least this seems to be the case, and this definitely should be considered when planning or selecting early childhood science experiences.

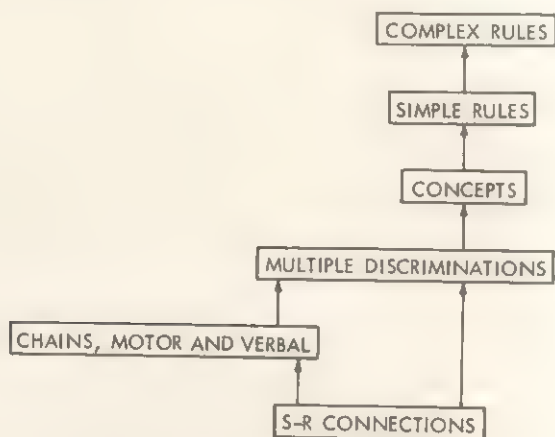
A second major implication stems from consideration of the stagewise cognitive development which is central to Piagetian theory, as the stages may be considered as boundaries that limit, though perhaps to a lesser degree than Piaget envisages, the capability of the child to learn and perform a given task. This would imply that the curriculum's activities be analyzed in terms of the logical operations inherent in them, and decisions must be made as to whether or not the child, at some particular age and developmental level, can operate at the cognitive level that the operations demand.

A further implication of developmental psychology for early childhood science education arises from the view that intelligence develops through the dual functioning of the invariants of assimilation and accommodation. This would imply that the spacing of learning activities is a very important factor in planning an instructional program. In other words, Piagetian theory supports the use of the "spiral" curriculum even at the unit stage.

2. *HUMAN LEARNING*. Finally, the psychology of learning should be considered, as many decades of work have led to a deeper understanding of human learning. Most representative of this are the associationist approach to learning and the research on reinforcement theory.

Psychologists have contributed to our understanding of how particular kinds of learning take place. Of particular importance has been the approach Gagné has taken. Gagné (1965) views learning as hierarchical, with one step or stage forming the prerequisite for further learning and for more difficult and complex behaviors. The hierarchical approach has the advantage of forcing the teacher or researcher to first decide upon what he expects the child to be able to do, and then to set the conditions of learning, starting from where the child is, so that the desired behaviors can be reached and assessed.

This approach offers an alternative proposal for the explanation of Piagetian cognitive development (Gagné, 1966) as *learning* plays a fundamental role and is distinguished from development even though they are certainly related. Gagné's model stresses the cumulative effects of learning which can account, at least within certain limitations, for behavioral development. The general hierarchical sequence may be summarized as follows.



The main point here is that perhaps a highly general principle such as conservation of substance may be analyzable in terms of learning conditions rather than the unfolding or development of logical structures and the like.

As discussed by Jensen (1966), there has been a movement within these areas to extend the simple S-R model to paradigms that involve various mediational processes and hierarchies of association chains. Rohwer (1966) has helped to illuminate the role of language through work on

serial and paired-associate learning tasks. Although many researchers have shown the importance of language to cognitive development of the individual's ability to use potential verbal mediators is still open to question. The writings of Luria (1957; 1961) and Vygotsky (1962) view "the word" as a hastener of mental processes and development. Or, as Brown (1956) has pointed out, words can serve as a "lure to cognition."

There are several ways in which the research guidelines in this section might be woven together.

One way is suggested by Whiteman (1964) who has attempted to interrelate the concepts of factors from psychometrics, learning set from learning theory, and operation from Piaget's work. His interrelations build around two characteristics of mental functioning: consistency and hierarchical organization of levels.

A second way might be through a "whole child" approach as described by Frank (1963). Frank suggests that the physical and mental dimensions of the growing child can be viewed as a dynamic configuration which cannot be parted without losing or destroying understanding of the basic processes involved.

A third way might be through Langer's assumption that man is most characteristically a user of symbols. To Langer (1958) man's humanity rests upon his ability to use symbols in order to produce whatever meanings there are in living, and through these symbols to communicate these meanings to his fellow man.

3. *AFFECTIVE OR MOTIVATIONAL FACTORS.* This area of research has been receiving more and more attention, as it is now realized that such factors as the individual's concept of self, and his attitudes towards school and learning are largely derived from the culture in general and his social and familiar milieu in particular. For example, the work of Wilson (1963) gives us insights into the influences of the child's peers, and Coles (1963) points out clearly how one's evaluation of self and society are affected by the social position in which one finds himself. And, as Bloom (1964) pointed out, the younger the individual, the greater effect environment will have on his subsequent development.

In answering the question "How does early experience work?" Hebb (1949) wrote that it "operates to establish perceptual elements." These elements, in Hebb's scheme, could be organized in the various senses, and modes for the foundation of all later environment would be laid. But, regardless of how early environment works, we know it strongly affects the individual, his aspirations, and his attitudes.

The complex and subtle ways in which the home environment effects educational achievement has only lately been the subject of systematic research. Only part of the educational achievement of children can be explained by status characteristics of the home, which is the aspect at which people most generally look. For example, Kahl (1953) found parental aspiration to be a more crucial factor than social class in

explaining educational achievement. Further work attempting to delineate certain process variables within the home and correlate these with general scholastic achievement and intelligence was done by Wolf (1963) and Dave (1963).

Dave hypothesized six relevant home environment variables that would probably be relevant to educational achievement. The variables were:

- a. Achievement Press.
- b. Language models in the home.
- c. Academic guidance in the home.
- d. The stimulation in the home to explore various aspects of the environment.
- e. The intellectual interests and activities in the home.
- f. The work habits emphasized in the home.

The six variables were broken down into twenty-two process characteristics which were used to summarize and rate the mothers' responses to an interview schedule. Dave obtained an overall correlation of .80 with the total score on an entire achievement test battery.

More work needs to be done in this area, for the tremendous importance that the environmental milieu has for individual development, especially at the early ages, mandates its consideration. To achieve the desired outcomes of early science education, we must consider the environment (both macroscopic and microscopic) from which the child comes.

THE DISCIPLINE

It has been suggested by Phenix (1958) and Schwab (1964) that the scholarly disciplines can be viewed not only as sources of what is "known" but also as sources of ways of "coming to know." That is, the disciplines serve the dual function of (a) an organized body of knowledge and (b) a method of arriving at, validating, and developing further that knowledge. As Kuhn (1962) pointed out, the combination of the duality gives a paradigm for understanding and dealing with nature and natural phenomena, and the questions that one asks are largely determined by the paradigm employed which, in turn, dictates the type of answer that is meaningful and consistent within the framework of the problematic situation. Thus the solution to any problem is tentative. That is to say, it rests upon, or is derived from, a matrix of changing paradigms, different problematic situations, and a relativism that encompasses the entire process.

Relating the idea of the scientific explanation to early childhood science education places an emphasis not on a complete or "true" understanding of nature, but on those understandings which can be meaningful to the

child at his particular age or stage of development (both experiential and psychological). In other words, the explanation is relative—relative to the child, his experiential and maturational development, the problematic situation as defined by the child, the operations used, and the context within which the concepts involved were developed. An explanation then is meaningful only in a timeplace setting, and that which constitutes an explanation for one child at any given time may not for another child at the same time.

Several attempts have been made to utilize the “ways of knowing” within frameworks of child development research.

1. *The Science Curriculum Improvement Study (SCIS)*. This study is designed to lead children into the exploration and conceptualization of the physical world in ways that deliberately parallel Piaget’s stages. Children experiencing the project are first asked to describe, compare, and classify static objects in their world by their physical properties. Such experiences form the basis for later work with measurements, interactions, and systems of objects.

2. *The American Association for the Advancement of Science (AAAS)*. This program places an emphasis upon the processes by which information is gathered and manipulated. Through carefully planned hierarchies, children receive sequential experiences that lead to carefully defined behavioral objectives.

3. *Beginning Science—A Modern Approach*. This program for very young children (Holt, Rinehart and Winston, Inc.) combines a Piagetian framework with a hierarchical sequence of process experiences within the major science fields.

Millie Almy’s work (1966) may give some guidelines as to the value of these and other such programs. Her work is presently attempting to measure changes in children’s logical thinking as a result of exposure to the SCIS and AAAS programs.

Important at this point is the need for longitudinal research and ongoing evaluation of the many new programs.

THE TEACHER

In attempting to seek the important elements that compose instruction, one is first confronted with the problem that not enough of the good instructional techniques have been identified, described, or organized in a way that will allow one to reproduce more of them on a consistent basis. Secondly, one is not even sure what the necessary elements are or if some still need to be created.

Unfortunately the science of instruction is still in a very primitive state. Major studies have attempted to correlate teaching “methods” with various teacher characteristics of student outcomes. To date, the results from these studies have proved inconclusive.

Bellack and Davitz (1965) have suggested that researchers begin to systematically describe what it is that takes place between teachers and students in different types of early childhood science programs. They feel that we need to know the ways in which teachers structure classroom experiences—especially the kinds of responses that are solicited from students and the kinds of operations students are asked to perform.

Along this line, some descriptive research has been started. The work by Flanders (1960), Hunter (1966), and Amidon (1967) have been the most promising by providing observational techniques and categories of instruction for analysis. Although scaling varies among the authors, the basic technique remains constant.

Unpublished as yet is Mary Rowe's (1967) work at Columbia University. Utilizing a simplified self analysis technique to aid and train teachers in science-micro-teaching situations, the training presently consists of a teach, feedback, and analysis sequence followed by a reteach, feedback, and analysis sequence. Analysis is made of verbal behavior through teacher collaboration and a modified Flander's observation-coding system.

The unpublished work of Frank Carus at the University of California, Berkeley, opens new directions in an attempt to evaluate and change teachers' modes of instruction. His research utilizes the video-taping of classroom performances with self evaluations coupled with a psychogalvanic skin response device that measures emotional reactions and verbal interpretations pertaining to performances.

Interest and research in the act of teaching and the total learning environment is growing. As it does, we, as science educators, should begin utilizing the many theories and studies which give us clearer understandings of the many dimensions which make up effective instruction. We should be seeking the kinds of materials, procedures, and settings which can not only be preplanned and provided for by teachers, but which will have a high probability concerning the fruitful development of the human potential in all children.

References

- Almy, Millie and E. Chittenden. *Young Children's Thinking: Studies of Some Aspects of Piaget's Theory*. New York: Bureau of Publications, Teachers College, Columbia University, 1966.
- Amidon, E., *Improving Teaching; The Analysis of Classroom Verbal Interaction*. New York: Holt, Rinehart and Winston, Inc., 1966.
- Bellack, A. A. and J. R. Davitz. *The Language of the Classroom. Meanings Communicated in High School Teaching*. Cooperative Research Project No. 1497, U.S.O.E. New York: Institute of Psychological Research, Teachers College, Columbia University, Park I, 1963; Part II, 1965.
- Bloom, B. S. *Stability and Change in Human Characteristics*. New York: Wiley, 1964.
- Brown, R. W. "Language Categories." In J.S. Bruner, J. J. Goodnow, and C. A. Austin (eds.), *A Study of Thinking*. New York: Wiley, 1956.

- Carlson, J. S. "Effects of Instruction on the Concept of Conservation of Substance." *Science Education*, 1967, 51, 46-51.
- Coles, R. *The Desegregation of Southern Schools: A Psychiatric Study*. New York: Anti-Defamation League of B'nai B'rith, July 1963.
- Dave, R. H. *The Identification and Measurement of Environmental Process Variables That Are Related to Educational Achievement*. Unpublished Ph.D. Dissertation, University of Chicago, 1963.
- Flanders, N. A. *Teacher Influence, Pupil Attitudes, and Achievement: Studies in Interaction Analysis*. Cooperative Research Project No. 397. Minneapolis: University of Minnesota, 1960.
- Frank, L. K. "Human Development: An Emerging Scientific Discipline." In A. J. Solnit and Sally A. Provence (eds.), *Modern Perspectives in Child Development*. New York: National Universities Press, 1963.
- Gagne, R. M. *The Conditions of Learning*. New York: Holt, Rinehart and Winston, Inc., 1965.
- Hebb, D. O. *The Organization of Behavior*. New York: Wiley, 1949.
- Hunter, Elizabeth and E. Amidon. *Improving Teaching*. New York: Holt, Rinehart, and Winston, Inc., 1966.
- Jensen, A. R. "Verbal Mediation and Educational Potential." *Psychology in the Schools*, 1966, 3, 99-109.
- Kahl, J. A. "Education and Occupational Aspirations of 'Common Man' Boys." *Harvard Educational Review*, 1953, 23, 186-203.
- Kendler, H. H. and Tracy S. Kendler. "Effect of Verbalization on Reversal Shifts in Children." *Science*, 1961, 134, 1619-1620.
- Kendler, Tracy S. "Learning Development and Thinking." In E. Harms (ed.), *Fundamentals of Psychology: The Psychology of Thinking*, *Annals of New York Academy of Sciences*, 1960, 19, 52-65.
- Kuhn, T. S. *The Structure of Scientific Revolutions*. Chicago: University of Chicago Press, 1962.
- Langer, Susanne K. *Philosophy in a New Key: A Study of the Symbolism of Reason, Rite and Art*. Mentor Books, New York: New American Library, 1958.
- Luria, A. R. "The Role of Speech in the Formation of Temporary Connections." In B. Simon (ed.), *Psychology in the Soviet Union*. Stanford, California: Stanford University Press, 1957.
- Luria, A. R. *The Role of Speech in the Relation of Normal and Abnormal Behavior*. London: Pergamon Press, 1961.
- Piaget, J. *The Language and Thought of the Child*. New York: Harcourt Brace, 1926.
- Phenix, P. H. *Realms of Meaning: A Philosophy of the Curriculum for General Education*. New York: McGraw Hill, 1958.
- Rohwer, W. D., Jr. "Mental Menomonic in Early Learning." Paper presented to the University of California Extension Seminar on Pre-School and Early School Enrichment, Berkeley, March, 1966.
- Rowe, Mary. "Use of Micro-Teaching Situations to Train Elementary Teachers in a New Science Program." Unpublished paper presented to the North Eastern Regional Conference of the N.S.T.A., November, 1967.
- Schwab, J. J. "Problems, Topics, and Issues." In S. Elam, *Education and the Structure of Knowledge*. Fifth Phi Delta Kappa Symposium on Educational Research. Chicago: Rand McNally, 1964.
- Vygotsky, L. *Thought and Language*. New York: Wiley, 1962.
- Whiteman, M. "Intelligence and Learning." *Merrill-Palmer Quarterly*, 1964, 10.

- Willson, A. H. "Social Stratification and Academic Achievement." In A. Passow (ed.), *Education in Depressed Urban Areas* New York: Teachers College Bureau of Publications, 1963.
- Wolf, R. M. "The Identification and Measurement of Environmental Process Variables Related to Intelligence." Unpublished Ph.D. Dissertation University of Chicago, 1964.

RECENT CURRICULUM DEVELOPMENTS IN ELEMENTARY SCIENCE

INTRODUCTION

The rapid growth of the movement to stress the process approach in the teaching of science created a strong impetus for the development of new programs that would be based upon this process approach. Action came first at the secondary level, where the need was more urgent. A number of experimental curriculum study projects were created, supported for the most part by the National Science Foundation, for the purpose of producing new high school science courses.

The high school projects—and their courses as well—are known by such titles as PSSC (Physical Science Study Committee), HPP (Harvard Project Physics), CHEM Study, (Chemical Education Material Study), CBA (Chemical Bond Approach), BSCS (Biological Sciences Curriculum Study), and ESCP (Earth Science Curriculum Project). They already have had a profound effect on the teaching of high school science.

Once the high school projects were under way, attention began to be turned to the junior high school and especially to the elementary school. Today there are a variety of curriculum study groups on elementary science in operation, sponsored by a number of agencies. All are concerned with the process approach, but they differ in the degree with which they include and structure the science content in the units and other teaching materials they are developing.

A highly significant feature of these new programs, both elementary and secondary, is the unprecedented large-scale involvement of scientists in the development of the programs. Scientists are initiating and directing almost all of the new curriculum study projects, and the impact of their philosophy and method of operation is quite noticeable. An examination of the new programs reveals strong similarities in the statements of their objectives, in the methods they use for teaching science, and in the kinds of materials they are producing.

Another significant feature of these new programs is the great financial

support they have received. This has made it possible to employ the services of leading scientists and science teachers, maintain nationwide committees and writing teams, develop a wealth of teaching materials, test these materials in a large number of schools, and then rewrite and retest these materials as often as needed. Funds are also available for publicizing the work of the projects by the dissemination of bulletins, progress reports, and samples or illustrations of the developed teaching materials.

Since all the new programs in elementary science are in various stages of development, it is still too soon to evaluate them properly. However, enough materials have been produced to permit a preliminary evaluation of their effectiveness and to provide some prognosis as to the ultimate accomplishments of the programs.

First, their emphasis on process is a breakthrough in the teaching of elementary science. For the first time the entire country has become very much aware that process must be an integral part of a science teaching. Second, the teaching materials seem to be enthusiastically received by both teachers and children. The materials are structured in great detail, so that the teacher can use them with little or no difficulty. Third, the programs will affect efforts to revise existing science curriculum guides in the schools, because specific provision will now have to be made for the teaching of process as well as content. Fourth, the programs will have an effect upon the kinds of in-service activities conducted for the teachers.

There are also a few criticisms of the programs, which most likely will be corrected by the time the programs are fully developed. First, many persons think that some programs stress process too much at the expense of content. These persons believe that the programs should include a structure of science content, with scope and sequence, because both content and process are equally important and mutually interdependent. Second, the teaching materials do not make enough provision for individual differences. Third, the teaching materials of some programs are so highly structured that they hamper the distinctive style and technique of many competent teachers. Fourth, there is not enough real evaluation of the materials, with too much consideration being given to the testimonials of teachers and the displays of enthusiasm by the children.

THE AAAS PROJECT: SCIENCE—A PROCESS APPROACH*

AAAS Commission on Science Education

The Commission on Science Education of the American Association for the Advancement of Science (AAAS) is supported by the National Science Foundation. The preparation and evaluation of new science materials for the elementary school has been the purpose and major activity of the Commission since its establishment. The materials that are being developed consist of a series of exercises designed to improve the child's skill in using the processes of science. It is the contention of the Commission that science is best taught as a procedure of inquiry and that curricular designs should be guided by this philosophy. The science content in the materials is drawn from various fields in science.

The development of an elementary science curriculum called *Science—A Process Approach* is now approaching completion. This curriculum, for children in kindergarten and grades one through six, has been developed by the Commission on Science Education of the American Association for the Advancement of Science. The five-year effort has been financially supported by the National Science Foundation, and has involved the enthusiastic participation of more than a hundred scientists and educators, representing a wide spectrum of backgrounds, interests, and specialized knowledge.

Initial plans for the design of this new curriculum were formulated in two conferences held in the summer of 1962. On the basis of these conferences, the Commission on Science Education outlined a projected elementary science program which would emphasize the laboratory method of instruction and would focus upon ways of developing basic skills in the processes of science. The processes include observing, classifying, measuring, predicting, and other skills needed for scientific investigations. The annual cycle of activities which has been repeated each year has followed this sequence: (1) planning for development, during winter and spring; (2) a "summer writing conference" of scientists and teachers; (3) a fall period of revision, editing, and publication of

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experimental materials; (4) a simultaneous activity, beginning in the fall and extending to the next summer, of trying out the newly developed materials in a group of participating schools in various parts of the country.

Since 1964, a *Newsletter* describing important events and outcomes of this developmental cycle has been published. A summary of the program's history is given in the *Newsletter*, Volume 3, No. 2 (1967).

CHARACTERISTICS OF THE PROGRAM

Science—A Process Approach shares certain purposes and characteristics with other modern science curricula. Like them, it is designed to present instruction which is intellectually stimulating and scientifically authentic. Like other programs, it is based upon the belief that an understanding of the scientific approach to gaining knowledge of man's world has a fundamental importance as a part of the general education of any child.

The program also has characteristics which make it different from other curricula in elementary science. The noteworthy and distinctive features of *Science—A Process Approach* may be summarized as follows:

1. Instructional materials are contained in booklets written for, and used by, the teacher. Accompanying kits of materials are designed for use by teacher and children. Except for certain work sheets in the later grades, there are no printed materials addressed to the pupil. What the teacher does is to organize and set up science problem situations designed for participation by the children.
2. The topics covered in the exercises sample widely from the various fields of science. The exercises are ordered in sequences of instruction to provide a developmental progression of increasing competence in the processes of science.
3. Each exercise is designed to achieve some clearly stated objectives. These are phrased in terms of the kinds of pupil behavior which can be observed as outcomes of learning upon completion of the exercise.
4. The coverage of fields of science is broad. Mathematics topics are included, to be used when needed as preparation for other science activities. Some of the exercises draw from the social and behavioral sciences. Most involve principles in physics, biology, and chemistry, with a lesser representation of earth sciences and astronomy.
5. What is to be learned by the children is an accumulative and continually increasing degree of understanding of, and capability in, the processes of science. Progress begins in the kindergarten with observation and description of object properties and motion, and advances through the sixth grade to the design and conduct of scientific experiments on a variety of topics.

6. Methods for evaluating pupils' achievement and progress are an integral part of the instructional program. Each exercise contains a test of pupil achievement reflecting the objectives of the exercise and providing means of assessing its outcomes. In addition, separate measures have been developed for use in determining pupil attainments in process skills prior to instruction.
7. A comprehensive text for the education of teachers is also an integral part of the program. This includes essential general information on the science principles and processes involved in the program, and a set of exercises providing opportunities for teachers to practice relevant instructional techniques.

THE MEANING OF PROCESS

There are a number of ways of conceiving of the meaning of "process" as exemplified in *Science: A Process Approach*. First, perhaps, it should be mentioned that an emphasis on process implies a corresponding de-emphasis on specific science "content." Of course, the content is there: the children examine and make explorations of solid objects, liquids, gases, plants, animals, rocks, and even moon photographs. But, with some few notable exceptions, they are not asked to learn and remember particular facts or principles about these objects and phenomena. Rather, they are expected to learn such things as how to observe solid objects and their motions, how to classify liquids, how to infer internal mechanisms in plants, how to make and verify hypotheses about animal behavior, and how to perform experiments on the actions of gases. For example, in an exercise on the movement of liquids in materials [Part E], the children learn to design and carry out experiments on the relation between kinds of materials and rate of movement of liquids within them, including the control and manipulation of relevant variables, but they are not required to learn particular facts about the rate of liquid movement in blotting paper, fabrics, sand, clay, or other materials employed in the exercise. Such facts may be incidentally learned, and may be useful to the child, but the primary objective is one of learning to carry out the process of controlling variables in an experiment.

A second meaning of process centers upon the idea that what is taught to children should resemble what scientists do: the "processes" that they carry out in their own scientific activities. Scientists do observe, and classify, and measure, and infer, and make hypotheses, and perform experiments. How have they come to be able to do these things? Presumably, they have learned to do them, over a period of many years, by practicing doing them. If scientists have learned to gain information in these ways, surely the elementary forms of what they do can begin to be learned in the early grades. This line of reasoning does not imply the

purpose of making everyone a scientist. Instead, it puts forward the idea that understanding science depends upon being able to look upon and deal with the world in the ways that the scientist does.

The third and perhaps most widely important meaning of process introduces the consideration of human intellectual development. From this point of view, processes are in a broad sense "ways of processing information." Such processing grows more complex as the individual develops from early childhood onward. The individual capabilities that are developed may reasonably be called "intellectual skills," a phrase which many would prefer to the term "processes."

When one considers processes as intellectual skills, certain general characteristics become apparent. One of the most important is the degree of generalizability one can expect in human capabilities of this sort. The typical development of intellectual skills, as Piaget's work amply reminds us, is far from the very concrete and specific to the increasingly abstract and general. Highly general intellectual skills are typically formed over a period of years, and are thought to depend upon the accumulated effects of learning a considerable variety of relatively concrete principles. Accordingly, the skills which *Science—A Process Approach* is designed to establish begin in highly specific and concrete forms, and increasing generality of these skills is systematically provided for by a planned progression of exercises. Evidence shows that these skills do generalize to a variety of new situations (*Newsletter*, 1967, Volume 3, No. 3, *An Evaluation Model and Its Application*, 2nd Report, 1968). The instructional program of *Science—A Process Approach* attempts to deal realistically with the development of intellectual skills, in the sense that the goals to be achieved by any single exercise are modest. In a longer-term sense, substantial and general intellectual development is expected to result from the cumulative effects of an orderly progression of learning activities.

PROCESSES AND INTELLECTUAL DEVELOPMENT

There is, then, a progressive intellectual development within each process category. As this development proceeds, it comes to be increasingly interrelated with corresponding development of other processes inferring, for example, partakes of prior development of skills in observing, classifying, and measuring. The interrelated nature of the development is explicitly recognized in the kinds of activities undertaken in grades four through six, sometimes referred to as "integrated processes," including controlling variables, defining operationally, formulating hypotheses, interpreting data, and as an ultimate form of such integration, experimenting.

A brief description of the expected sequence of development in both

basic and integrated process categories is as follows. More complete descriptions of these processes are contained in the *Commentary for Teachers* (1968).

OBSERVING. Beginning with identifying objects and object-properties, this sequence proceeds to the identification of changes in various physical systems, the making of controlled observations, and the ordering of a series of observations.

CLASSIFYING. Development begins with simple classifications of various physical and biological systems and progresses through multi-stage classifications, their coding and tabulation.

USING NUMBERS. This sequence begins with identifying sets and their members, and progresses through ordering, counting, adding, multiplying, dividing, finding averages, using decimals, and powers of ten. Exercises in number-using are introduced before they are needed to support exercises in the other processes.

MEASURING. Beginning with the identification and ordering of lengths, development in this process proceeds with the demonstration of rules for measurement of length, area, volume, weight, temperature, force, speed, and a number of derived measures applicable to specific physical and biological systems.

USING SPACE-TIME RELATIONSHIPS. This sequence begins with the identification of shapes, movement, and direction. It continues with the learning of rules applicable to straight and curved paths, directions at an angle, changes in position, and determinations of linear and angular speeds.

COMMUNICATING. Development in this category begins with bar graph descriptions of simple phenomena, and proceeds through describing a variety of physical objects and systems, and the changes in them, to the construction of graphs and diagrams for observed results of experiments.

PREDICTING. For this process, the developmental sequence progresses from interpolation and to extrapolation in graphically presented data to the formulation of methods for testing predictions.

INFERRING. Initially, the idea is developed that inferences differ from observations. As development proceeds, inferences are constructed for observations of physical and biological phenomena, and situations are constructed to test inferences drawn from hypotheses.

DEFINING OPERATIONALLY. Beginning with the distinction between definitions which are operational and those which are not, this developmental sequence proceeds to the point where the child constructs operational definitions in problems that are new to him.

FORMULATING HYPOTHESES. At the start of this sequence, the child distinguishes hypotheses from inferences, observations, and predictions. Development is continued to the stage of constructing hypotheses and demonstrating tests of hypotheses.

INTERPRETING DATA. This sequence begins with descriptions of graphic data and inferences based upon them, and progresses to constructing equations to represent data, relating data to statements of hypotheses, and making generalizations supported by experimental findings.

CONTROLLING VARIABLES. The developmental sequence for this "integrated" process begins with identification of manipulated and responding (independent and dependent) variables in a description or demonstration of an experiment. Development proceeds to the level at which the student, being given a problem, inference, or hypothesis, actually conducts an experiment, identifying the variables, and describing how variables are controlled.

EXPERIMENTING. This is the capstone of the "integrated" processes. It is developed through a continuation of the sequence for controlling variables, and includes the interpretation of accounts of scientific experiments, as well as the activities of stating problems, constructing hypotheses, and carrying out experimental procedures.

DESCRIPTION OF INTELLECTUAL DEVELOPMENT

Descriptions of these sequences of intellectual development serve a number of purposes in the execution of the educational program embodied in *Science: A Process Approach*. These descriptions are contained in behavioral hierarchies, which bear a derivative relation to the learning hierarchies for smaller portions of various curricula. A chart depicting the behavioral hierarchies for all of the simpler processes has recently been published (*Process Hierarchy Chart*, 1967), and an explanation of them is also given in booklets introducing each Part, entitled *Description of the Program*.

The behavioral hierarchies constitute the "skeleton" of *Science: A Process Approach* and the rationale for selecting and ordering the sequence of exercises. Thus the behavioral hierarchies orient the teacher to the purposes of the program, or of any portion of it. The teacher may examine the progression of behavioral development depicted in these hierarchies, and derive from them a view of where teaching starts and where it is expected to go. In addition, they show the interrelationships between any one exercise and others which precede or follow it, including those primarily devoted to other processes. To aid the teacher in

maintaining this viewpoint towards the progressive development of processes, there is included in each exercise a section showing the relevant preceding steps and subsequent steps in the behavioral hierarchy. This section is, in actuality, simply a small portion of the entire hierarchy, providing the teacher with a rather specific view of what has gone before and what is coming next. The interpretation of such diagrams is expected to be: (1) here are the prerequisites for the present exercise; (2) here is what the child is expected to learn in this exercise; and (3) this is what the exercise will prepare him to undertake in later learning.

The second major use of the behavioral hierarchies is as guides to the assessment of student achievement and program evaluation (*Newsletter*, 1967, Volume 3, No. 3). Initial evaluation of the student, to determine whether or not he has achieved the objectives of each exercise, is carried out by performance tests based upon the objectives stated in the exercises themselves. Such tests, however, are designed to be consistent with the behavioral hierarchies, so that in each case what is being measured is a new achievement, and not something that has already been achieved as a result of some earlier exercise.

In addition, provision must be made to measure achievement in a sense other than as the immediate effects of instruction; in fact, in a developmental sense. The basis for such measurement is again the developmental sequence of the behavioral hierarchy, represented in a test which attempts to assess how far a pupil has progressed in each process (*Science—A Process Approach, The Process Instrument*, 1968). Finally, the hierarchies also guide the development of measures of achievement which are "terminal" to the program, insofar as they help to define what the minimum set of behaviors may be for children who have participated in the program for a period of years.

PURPOSES OF THE PROGRAM

The major characteristics of *Science—A Process Approach* which have been described surely serve in large part to convey what the program is all about. Some additional understanding of the approach, however, may be gained from an account of the purposes which have guided the effort. An important statement of these purposes was prepared at an early stage of development by a committee of the Commission on Science Education (*Science—A Process Approach, Commentary for Teachers*, 1965). In addition, several papers dealing with the goals of various aspects of the development were prepared at different points along the way and are collected together under the title *The Psychological Bases of Science—A Process Approach* (1965).

GENERAL EDUCATION From the outset, it has been a guiding purpose to develop a curriculum which could become part of the general

education of every child. The goal has not been to produce students of science who have a large amount of highly specialized knowledge. Rather, the aim is for every child to acquire the basic knowledge and point of view which provide him with a highly generalized method of gaining an understanding of himself and the world in which he lives.

PREPARATION FOR SYSTEMATIC STUDY OF SCIENTIFIC DISCIPLINES. Another important guiding purpose has been to provide the student in the elementary grades with some highly generalizable intellectual skills, and some knowledge of scientific procedures for gaining new knowledge, which can serve as a springboard for later study of any of the sciences. There are some very basic ideas, it is believed, which are important to the understanding of systematic science, and which cannot be readily identified as portions of the traditional elementary curriculum. It is these ideas that are intended to be represented as the "processes" of the new science curriculum.

GENERALIZABILITY OF KNOWLEDGE. A related aim is that of providing the child with the kind of knowledge that is generalizable to new situations. In part, this is accomplished by the use of a variety of content. In part, it is attempted by asking the child to practice making generalizations from one field of science to another. Controlling variables in an experiment on kinetic energy may be followed by an exercise that poses a problem of controlling variables in plant growth.

LEVEL OF ACHIEVEMENT. Certainly, the program aims for a level of achievement in understanding science and making scientific investigations which has not heretofore been attained by elementary school students. The purpose is to give these children capabilities for thinking and acting in the realm of science which go far beyond what has previously been customary. It is hoped that such capabilities may be applied in all their pursuits, not solely to the further study of scientific subjects.

INTELLECTUAL CHALLENGE. The materials of the program were prepared with the aim of presenting children with intellectual challenges. Pupils are required to remember few "facts," and those few will most probably be retained without effort. However, they are frequently asked to think, to use reasoning, and to invent methods and explanations. This is considered to be an important part of what is meant by learning to use science "processes."

PUPIL INTEREST. The well-known principle of proceeding in instruction from the familiar to the unfamiliar is used throughout the program. The attempt is made to appeal to initial pupil interest, and to maintain it as new problems are introduced. Thus, one important goal of instruction is to bring about a broadening of pupil interest in the many fields of science. It is hoped that the child will come to recognize many new problems, previously unknown to him, which can be viewed

scientifically; and that over the course of the program he will develop a lasting interest in science, whether or not he chooses it for a life work.

ACHIEVEMENT MOTIVATION. Besides the motivation of curiosity and intellectual challenge, the program intends to make use of achievement motivation. Comments from teachers and the measured achievements of children during the tryout period have been used as bases for revisions and adjustments in the exercises designed to accomplish this purpose. The exercises are aimed at *all* children, not solely the bright ones. The objectives are intended to be not too difficult for the vast majority of children to achieve. When they are achieved, this accomplishment will, it is hoped, reward the child and thus contribute to the maintenance of his interest in further exploration of science and its processes.

ACCOMPLISHMENTS

The goals of *Science—A Process Approach*, although moderately ambitious, appear to be attainable. What evidences are there, at the present time, that progress is being made toward these goals? What accomplishments can be described?

A SYSTEMATIC COURSE OF STUDY. The instructional materials of *Science—A Process Approach* (Parts A-C, 1967; Parts D and E, 1968; Parts 6 and 7, 1967) provide the basic evidence that a systematic course of study in the processes of science has been developed. Successive exercises in each process build upon earlier exercises in a progressive sequence, while at the same time variations in subject matter are deliberately introduced.

Empirical findings concerning the existence of ordered relationships among the exercises, in the sense that successful completion of one contributes to the learning involved in a subsequent one, have been described in reports of the results of pupil testing (*Newsletter*, 1967, Volume 3, No. 3; *An Evaluation Model and Its Application*, 2nd Report, 1968). Additional findings have been obtained, and are to be reported, by administering an individual test of performance in the various processes (*The Process Instrument*, 1968) to groups of children who have participated in the program for one or more years. In general, with some notable exceptions, it has been shown that achievement of lower levels of development in each process increases the probability of attaining subsequent steps in these intellectual skills. As for the exceptions, these have led to a re-examination of the exercises and the sequencing of developmental steps; and in many instances the latter have been reordered as reflected in the most recent Process Hierarchy Chart (1967).

CONTINUED REVISION FOR IMPROVEMENT. From the outset the materials of *Science—A Process Approach* have been subjected to periodic

improvement based upon information collected during tryouts in 15 school systems located in various parts of the country. Reports from teachers have provided systematic information on the ease of teaching, technical difficulties, degree of pupil enthusiasm, appraisals of pupil understanding, and related matters. Measures of competence administered to children upon the completion of each exercise have yielded data on the proportion of children achieving each of the defined objectives of the exercise. The target has been to have 90% of the children achieve 90% of the objectives. Each revision of the exercises, in four successive years for each part, has been based upon these findings regarding pupil achievement and teacher reception; and each revision has approached more closely the stated goals of the program. Comprehensive accounts of the information yielded by these two sources of data have been reported (*An Evaluation Model and Its Application*, 2nd Report, 1968).

BROAD COVERAGE OF SCIENCE. The booklets of *Science A Process Approach* exhibit the varied coverage of the fields of science which reflect the aims of the program. The distribution of content in relation to accepted categories of science is approximately as follows: Physical Science, 40 per cent; Life Science, 25 per cent, Mathematics, 18 per cent; Earth Sciences, 10 per cent; Social and Behavioral Sciences, 7 per cent.

AVAILABLE TEACHER PERFORMANCES. Another notable accomplishment of the program has been its concerted approach to the problem of orienting and educating teachers of elementary science. The need for materials for the education of teachers was recognized early, and much effort has been devoted to the preparation of a course and accompanying materials for the teacher who is preparing to teach the program. Emphasis is given in teacher education to the science processes and their relation to human intellectual development, in addition to helping teachers acquire the competencies included in *Science—A Process Approach* for application in the classroom. The *Commentary for Teachers* is actually much more than a commentary, for it contains carefully prepared self-instructional lessons relevant to each of the processes. The materials have been tried out and evaluated in several teacher workshops; and their latest form reflects revisions based upon systematic information collected within these sessions (to be reported later in an issue of the AAAS Commission on Science Education *Newsletter*).

Still another product of development is a guide intended for the leaders of sessions for teacher education, reflecting the science processes, their psychological bases, and the variety of science activities and teaching strategies to which they lead. The *Guide For In-service Instruction* (1967) incorporates brief instructional films, self-instructional booklets, and tests for diagnosis and evaluation of teacher learning.

STUDENT ACHIEVEMENTS. Reports of results on program evalua-

tion (*An Evaluation Model and Its Application*, 1968; *Newsletter*, 1967, Volume 3, No. 3) generally provide much favorable evidence regarding student achievements. For example, it has been found that immediate achievement measures indicate 90 per cent of the children to have acquired at least 70 per cent of the desired competencies for 97 of 102 exercises in Parts A through D. Further, 90 per cent of the children reached the 80 per cent level of achievement for all but fourteen of these exercises. When children who had participated in the program for one year were compared with children at the same grade level who had participated for three years, differences favoring the latter group ranged from two to twenty per cent. When achievements of a group of children from a low socioeconomic background were compared with those of medium and high levels of family income, it was found that although the former group completed fewer exercises, their success on the completed exercises was as high as that of the other children.

Other evidences of the effects of the program have yet to be gathered. More information will be sought on the lasting effects of this program. Answers are needed to such questions as what children know and what they are able to accomplish at the end of the fourth grade, the fifth, and the sixth, after having completed several years of *Science—A Process Approach*. In addition, it is hoped that evidence can be obtained of increased pupil interest in science, as well as an increased degree of the children's positive valuation of scientific activities after participation in the program over a period of several years.

EXPECTATIONS

What will a "graduate" of *Science—A Process Approach* be like? What will he know? What will he be able to do? These questions, of course, cannot be answered at the present time with any great degree of assurance. The evidence of what these children are like will have to come, after a period of years, from evidence of what they can accomplish in grades subsequent to the sixth. Perhaps also it will come from evidence of how they behave toward science in even later periods of their lives.

The following descriptions of what may be expected of a child who has completed the program are speculative, although stated in concrete terms. They represent goals which have given implicit guidance to the development of *Science—A Process Approach*. While the full attainment of these goals is greatly to be desired, even partial attainment would surely be viewed as a substantial indication of the program's effectiveness.

1. He will tend to apply a scientific mode of thought to a wide range of problems, including social ones, distinguishing facts from conjectures and inferences, and identifying the procedures required to obtain verification of hypotheses and suggested solutions.

2. He will be able to acquire an understanding of the structure of those particular scientific disciplines he pursues in junior and senior high school more rapidly and with less difficulty than is the case with **students today.**
3. In a printed account of a scientific experiment, using terms that are understood or defined, he will be able to identify the question being investigated, the variables manipulated, controlled, and measured, the hypothesis being tested, how such a test relates to the results obtained, and the conclusions which can legitimately be drawn.
4. In an oral account of a scientific experiment, given by a scientist using terms intended for laymen, he will be able to identify those elements of scientific procedure and findings mentioned in 3.
5. In an incomplete account of a scientific experiment, such as might appear in a newspaper, he will be able to infer, where necessary, the question being investigated and the elements of scientific procedure **described in 3.**
6. Given a problem amenable to scientific investigation, and within his understanding as to factual content, he will be able to design (and under certain conditions, carry out) one or more experiments to test hypotheses relevant to the problem.
7. He will show his appreciation of, and interest in, scientific activities by choices made in reading, entertainment, and other kinds of **leisure-time pursuits.**

To those who have developed the program, these predictions seem not unreasonable. They are things that should happen if and when they do, the truly important outcomes of *Science: A Process Approach* will be known.

ESS: THE ELEMENTARY SCIENCE STUDY*

Education Development Center

The Elementary Science Study (ESS) of Education Development Center is supported by the National Science Foundation. The primary objective of this project is to develop more meaningful science materials for the elementary school. These materials are designed so that they inherently draw for a flow of ideas originating from the curiosity of children. Little emphasis is given to the development of a sequential or continuing program with specific structure and assigned grade levels. The main purpose is to supply a variety of carefully thought out and tested materials which a school system may use in developing an elementary science curriculum.

The Elementary Science Study is one of many curriculum development programs in the fields of science, social studies, and mathematics under preparation at Education Development Center. The EDC is a private non-profit organization, incorporating the Institute for Educational Innovation and Educational Services Incorporated, begun in 1968 to develop new ideas and methods for improving the content and process of education.

ESS has been supported primarily by grants from the National Science Foundation. Development of materials for teaching science from kindergarten through eighth grade started on a small scale in 1960. The work of the project has since involved more than a hundred scientists and educators in the conception and design of its units of study. Among these scholars have been biologists, physicists, mathematicians, chemists, and teachers experienced in working with children of all ages from kindergarten through college.

Equipment, films, and printed materials are produced with the help of staff specialists as well as of the film studio, the photographic laboratory, and the production shops of EDC. At every stage of development, ideas and materials are taken into actual classrooms where children help shape the form and content of each unit before it is released to schools everywhere.

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ESS units are now being taught all over the United States and in some foreign countries. The role of ESS in several school systems is an active one, and these school districts serve as growing-points from which our ideas can expand to new areas. Teachers join us in experimental summer schools which we administer in conjunction with local school systems; other educators visit us during the year. Some join us for a time as staff members or consultants. Those who return to their home districts help introduce ESS materials to their colleagues.

In addition, we are working with various school systems and schools of education in consultant and advisory capacities. We conduct frequent workshops and seminars with pre-service and in-service teachers and with administrators, in order to develop more effective training techniques. Our staff members take part in national and regional meetings of educators and scientists.

Through the *ESS Newsletter* and other publications we are in touch with thousands of individuals and institutions. We hope you are among these, and we invite your comments and suggestions.

THE ESS APPROACH

The Elementary Science Study units differ widely, but they share a common approach to the teaching of science in elementary schools. Rather than beginning with a discussion of basic concepts of science, ESS puts physical materials into children's hands from the start and helps each child investigate through these materials the nature of the world around him. Children acquire a great deal of useful information, not by rote but through their own active participation. We feel that this process brings home even to very young students the essence of science—open inquiry combined with experimentation.

It is apparent that children are scientists by disposition: they ask questions and use their senses as well as their reasoning powers to explore their physical environments; they derive great satisfaction from finding out what makes things tick; they like solving problems; they are challenged by new materials or by new ways of using familiar materials. It is this natural curiosity of children and their freedom from preconceptions of difficulty that ESS tries to cultivate and direct into deeper channels. It is our intention to enrich *every* child's understanding, rather than to create scientific prodigies or direct all children toward scientific careers. We want children to be at home with modern technology, not to be intimidated by it. We have tried to incorporate both the spirit and the substance of science into our program in such a way that the child's own rich world of exploration becomes more disciplined, more manageable, and more satisfying.

THE UNITS

The basic elements which carry out the ESS approach are our units. They are of many different kinds, and they draw on many areas of the natural sciences and mathematics. Some can occupy a class period every day for several months. Some are intended for regular use over short periods of time; some for weekly classes over a longer period. Others can run concurrently with other units of study or can be left in the classroom for the children to come to again and again in their free time.

Some units involve living animals which the children work with and observe through part or all of the animal's life cycle. Some develop skills that are fundamental tools for all learning. Many can be related to other areas of study, such as social studies or reading, or can heighten the joys of aesthetic experience and of play. Certain units make highly sophisticated concepts available in delightful ways, even to children who are not yet old enough to write.

It is part of the ESS approach to avoid introducing the formal names of things and concepts before the reality is understood. In many cases the informal vocabulary we use in describing the activities of a unit has evolved naturally among children using that unit in trial classes. Students may learn the formal terminology and expand their useful vocabulary, but we hope they will know what they are talking about first. We want words to enrich understanding not interfere with—or substitute for—understanding.

In much the same spirit we recommend that common and inexpensive materials be used wherever possible, both for the sake of economy and so that students can relate the subject matter of the unit to their everyday experience.

In the course of developing our units we have found it worthwhile to abandon a great many conventional ideas about teaching. We want students not only to recognize scientific authority but also to develop both the confidence and the skills needed to question it intelligently. For this reason we feel it is necessary for the student to confront the real world and its physical materials directly, rather than through intermediaries such as textbooks.

We feel that the direction a unit takes should be determined, in large part, by the students, if they are to develop a personal involvement in, and commitment to, their work. We caution teachers against explaining things prematurely and against over-directing student activities. We prepare teachers' guides that suggest ways of managing the flexible procedure we recommend and that give teachers the background information they need. Classroom kits, student booklets, films, and equipment and materials which we supply or which can be found locally are the vehicles through which both students and teachers explore the units.

We have discarded the notion that a given area of inquiry is appropriate for only one age group, because we have seen that a unit may work well, though in different ways, with many age and ability levels.

Our units are designed to reach children from many backgrounds and with different abilities, in widely-differing school systems. They are taught successfully in big city schools and in suburban or small town systems all over the United States, in African villages and Latin American centers, in well-to-do or average communities as well as in slums, in special classes for the deaf or the blind, for the gifted or the retarded. They are intended for the teacher in the self-contained classroom as well as for the specialized teacher or consultant.

It is our belief that a unit can succeed in these many different classrooms only if we refrain from imposing a specified sequence of activities on the teacher. We feel strongly that teachers need the freedom to modify the units to suit the requirements of any given class, and so we suggest a variety of approaches and leave the choice of sequence to the teacher.

The units require good teaching. They afford teachers the opportunity to enlarge their roles. We see a need for teachers to help students observe, ask questions, design experiments, and assess the meaning of the results of these experiments. To do these things without telling or directing too much requires great restraint on the part of teachers, a restraint that is born of self-confidence and supported by confidence in and respect for children. We have seen our materials reinforce these qualities in teachers. We have also learned that in the long run these qualities are more important to the teaching of ESS units than is a substantive knowledge of science.

HOW A UNIT IS MADE

A unit of study begins with an idea; we are never sure how it arises. We provide facilities—laboratories, library, shops, materials—and give developers time to try out their inspirations on one another. Typically, discussion, consultation, argument, invention, and laboratory and shop work lead to an experimental teaching guide and trial equipment which are taken into classrooms by our own staff.

The interchange among developers, teachers, observers, and the students themselves leads to a series of revisions. Sometimes a unit is dropped at an early stage because it is unworkable. More often it is redirected toward new ends.

When a unit is ready to stand on its own, it is taught by cooperating teachers in a number of schools and revised on the basis of their experience. Such trial-teaching serves to pinpoint the range of ages for which a unit may be most appropriate, as well as to refine the choice or design of appropriate teaching materials.

Special equipment is then manufactured, sources for materials are located, printed matter is produced, release prints of films are made, and the unit is sent out to schools all over the country for trial teaching. Workshops are conducted to familiarize teachers and administrators with the unit so that they can use it as they think best.

Each unit is taught in fifty to one hundred trial classes over a period of two or three years before it is ready for commercial production. No unit is released until scientists and teachers agree that it is scientifically sound, communicates well to teachers and children, and adds a significant dimension to the learning experience.

CURRICULUM PLANNING

The enormous variety of schools and school systems in this country suggests that no group—ESS or any other—can design a single curriculum that will satisfy all conditions. Planning a curriculum involves decisions which can be made only with specific knowledge about the teachers, principals, students, parents, and finances in each case. We feel that the healthiest situation is one in which each school system decides what it wants to teach at every level and what it expects of students; into such a framework it can then fit those units which are most appropriate to the situation. We are happy to work with a school toward achieving a curriculum which will suit its individual needs.

EVALUATION

The evaluation of an ESS unit is a process that is implicit in the teaching of that unit. Because the teacher is actively involved in the study, she is continually aware of the degree of her students' participation and their learning success.

Formal evaluation is possible where the school or teacher feels it is necessary. Certain units lend themselves well to written examinations; we feel, however, that this is an incomplete way to evaluate a learning experience. For many of our units independent projects are suggested in the teacher's guide, and a student's ability to carry out one of these on his own is a measure of what he has learned.

Since much of what we hope to teach is basic to all learning, and since we offer fundamental intellectual tools and try to promote attitudes of inquiry, it is possible to judge what a child has learned from a given unit not only by the amount of information he retains, but also by his approach to new studies in science and in other fields, by the skills he has acquired, and by the habits of mind he evidences.

The most satisfying form of evaluation reported to us is a subtle one. Teachers tell us of children's excitement at what they are learning and of their enthusiasm for the ways in which they are learning. A student who

has hardly participated in class comes alive. A child who has been unsure of himself speaks up: "I know I am right because I tried it!"

To us, an interested class is a successful one.

SCIS: THE SCIENCE CURRICULUM IMPROVEMENT STUDY*

Robert Karplus and Herbert D. Thier

The Science Curriculum Improvement Study (SCIS) is supported by the National Science Foundation. The study is concerned with exploring a concept of science education based on communicating scientific literacy. The large-scale organization of the curriculum is determined by the structure of science, by the maturity of the pupils, and by the pupils' preconceptions. The organization of individual lessons is determined by the discovery method of concept development and by the needs of the learners.

The Science Curriculum Improvement Study is attempting to develop a teaching program to increase the scientific literacy in the school and adult populations. To accomplish this aim, the Study has to formulate a view of the nature and structure of science; it has to devise learning experiences that achieve a secure connection between the pupils' intuitive attitudes and the concepts of the modern scientific point of view; and it has to find how one can determine what the children have learned.

Since it appears that present knowledge is not adequate for this purpose, the Study is engaged in a research program that will eventually yield the necessary information. A science program constructed in this way will, it is hoped, have a pattern that is understandable by teachers and will not merely be a prescription to be followed blindly by them.

The general strategy of the Study is to confront the elementary school

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children with first-hand experience of natural phenomena and with intellectual challenges that will stimulate their further cognitive development. The Study may also shed some light on the acceptance by school systems and their communities of an educational program designed to create inquisitiveness, mental flexibility, and intellectual independence.

The function of education is to guide the children's development by providing them with particularly informative and suggestive experiences as a base for their abstractions. At the same time, children must be led to form a conceptual framework that permits them to perceive phenomena in a more meaningful way and to integrate their inferences into generalizations of greater value than they would form if left to their own devices.

It is important to stress the fact that the conceptual framework is an essential part of science, a part that can be developed in a properly guided substantive study of natural phenomena. A science curriculum should therefore be judged both on the opportunities it affords pupils for having stimulating experiences and on the conceptual hierarchy that these experiences nourish. The development that takes place in the absence of such instruction is haphazard and leads to many invalid generalizations that are serious obstacles to later learning.

In implementing a science curriculum that makes significant contributions to children's intellectual development, it is necessary to focus also on some shorter range goals. Intellectual development and scientific literacy are broad objectives which help to determine the overall curriculum strategy. They must, however, be supplemented by more specific shorter range goals to make possible spelling out of the teaching program in detail. These shorter range goals of SCIS are to acquaint pupils with specific examples of objects and organisms, to let them investigate definite examples of natural phenomena, and to help them develop skills of manipulating equipment and recording data.

The course outline of the curriculum is related to the hierarchical level of abstraction in the program. First level abstractions are the conceptions of matter, of living matter (including activity and growth), of conservation of matter (including the systems concept), and of variation in one property among similar objects. Second level abstractions are the conceptions of interaction (including casual relations or associations), and of relativity (geometrical relations or associations). Third level abstractions are the conceptions of energy (including energy transfer during interaction), of equilibrium, of steady state, and of behavior, reproduction, and speciation of living matter. The abstractions on the earlier levels have to be grasped before the ones on the later levels can become meaningful. Each abstraction can be illustrated on its own level, but it is further enriched by illustrations on the succeeding levels. Thus, for example, understanding of energy transfer both depends on and enlarges the understanding of interaction, the ability to isolate a system and subsystems, and the awareness of material objects.

The details of the classroom procedure are spelled out in teacher's manuals for several units at each of the levels mentioned above. Copies of these manuals are available at a nominal charge from the SCIS headquarters at the University of California in Berkeley. The program reflects as great a breadth of natural phenomena as is consistent with the concepts being developed. At present, six units are available in printed Preliminary Editions.

MATERIAL OBJECTS, a first level physical science unit, develops the concept that matter exists and has properties. This concept is one of the first abstractions a child is able to understand and deal with. The unit introduces children to the fundamental concepts of objects and their properties, and familiarizes them with the natural history of objects and their composition. It leads children to manipulate, describe, compare, and transform a broad range of objects including samples of wood, metal, plastic, granular materials, liquids, and gases. Here each child learns to recognize material objects in his own environment and to distinguish the objects themselves from their properties.

INTERACTION, a second level physical science unit, introduces the concept that changes observed in a group of objects are evidence of interaction of the objects with each other. In order to help pupils determine which objects interacted, the systems concept is introduced as a means of mentally separating the objects of interest from their environment. Examples of interaction-at-a-distance are included to de-emphasize the necessity of physical contact between interacting objects. Beginning with the manipulation of simple items such as a magnet and a paper clip and working up to the building of electric circuit testers, the unit provides opportunities to investigate examples of thermal, magnetic, and electric interactions. Through investigation with controlled experiments, the children become acquainted with regular patterns of behavior.

SYSTEMS AND SUBSYSTEMS, a third level physical science unit, expands the systems concept, which was originally invented for the children in an earlier unit. In this unit the children are presented with a variety of phenomena chosen from many subject areas of physical science. Their initial contact with these phenomena is provided through such common objects as a magnet and compass (magnetism), vinegar and washing soda (solutions), medicine dropper and syringes (liquids and gases), and sand and screens (mechanical action). Each area is investigated further through exploratory and discovery activities as children work with electric circuits, solutions, crystals, precipitates, the Whirly Bird pendulum, and many other materials, all provided in the equipment kit. Through their exploration of systems and subsystems concepts, the children are led to the recognition of variables and sharpen their discrimination of what is important to a particular outcome of a phenomenon from that which is also present but unimportant.

RELATIVITY, also a third level physical science unit, develops the concept that the position of an object can only be perceived, described, and recognized with reference to nearby objects. To enable pupils to overcome the limitations of conventional observations and their egocentric view of spatial relationships, Mr. O—the artificial observer—is introduced. The children are asked to describe directions as Mr. O would, thus gaining practice in shifting their point of view. Throughout the unit, the Relativity Puzzle Set is used to give the children direct, informal experiences in comparing distances, arrangements, relative positions, and directions as they seek to match the puzzle cards.

ORGANISMS, a first level life science unit, introduces the basic concept of an ecosystem: the relationship of a community of organisms within their environment. Focus in this unit is on the aquarium, an environment with transparent walls through which its inhabitants and their interrelationships can easily be observed. Questions about the changes that take place in the aquaria lead to the discovery of some of the basic processes, interactions, and conditions that are characteristic of the ecosystem. Fish, snails, algae, water fleas, and seedlings—all supplied as part of the equipment kit—provide the children with observations of birth, growth, death, and decay processes. Outdoor activities are also included where children discover how animals and plants interact with one another as well as with soil, water, atmosphere and sunlight.

LIFE CYCLES, a second level life science unit, continues the investigation of ecosystems by focusing on individual organisms. Through the study of the life cycles of selected plants and animals, children are able to increase their awareness of the difference between living and non-living objects. Seeds and bulbs are provided in the equipment kit, as well as frog eggs, fruit flies, and other animals. Observation of these plants and animals gives the children direct experience with such fundamental biological concepts as reproduction, growth, germination, metamorphosis, and biotic potential.

Other units are either already available in Trial Editions or in the process of being developed. In the physical sciences these include a fourth level unit called **POSITION AND MOTION**, a fifth level unit called **ENERGY SOURCES**, a sixth level unit called **MODELS FOR ELECTRIC AND MAGNETIC INTERACTION**, and another sixth level unit called **PERIODIC MOTION**. In the life sciences these include a third level unit called **POPULATIONS**, a fourth level unit called **ENVIRONMENTS**, a fifth level unit called **FOOD (ENERGY) TRANSFER**, and a sixth level unit called **ECOSYSTEM**.

At present there are SCIS trial centers at Teachers College of Columbia University, the University of California at Los Angeles, Michigan State University, the University of Oklahoma, and the University of Hawaii. In each of the centers, the SCIS program will be used by the laboratory elementary school of the center and/or neighboring public schools. In

addition, the preliminary publication program will make available to school systems materials developed by the SCIS study which can be tried out on an experimental basis.

The accomplishment of the long-term objectives and short-range goals of the Science Curriculum Improvement Study is dependent not only on the quality of the science program developed, but also the strategies used in the classroom when putting the program into effect.

First the classroom must be reorganized so that it resembles a laboratory in which children can have actual experiences with natural phenomena. A child may be involved in the science program on any or all of four levels. The first and minimal level of involvement is limited to reading about or being told about science. The second level of involvement includes teacher-pupil and pupil-pupil discussions about science. Both of these levels are completely verbal and abstract. The child's understanding is limited by his ability to understand the printed or spoken word and also by his ability to clearly express his own ideas.

The pupil is involved on a third level when the teacher or another pupil conducts a demonstration using science equipment and materials. While this is a step above the first two levels, it is still well short of the ideal—since the relationship of most of the class to the equipment and materials is passive.

Only on the fourth level of involvement do we approach the ideal. Here we find the individual pupil confronting the objects and systems he is studying. He manipulates, observes, and acts upon these objects and systems. His findings are his own and are determined by what happens as a result of his actions and manipulations. Consequently, he learns and experiences science first hand, rather than vicariously. He acquires a more realistic and concrete understanding of the phenomena that make up his environment.

The child can attain this fourth level of involvement only in a laboratory-type classroom. But he will not attain it—even in a laboratory-type classroom—unless the teacher takes on a new role.

A complete science curriculum which meets all the objectives outlined in this article (a lofty goal) would fall miserably short of its potential if used by a teacher or a group of teachers who see their role as imparters of information. Instead, the teacher must spend a great deal of time listening to children and observing their work on the fourth level of individual involvement with science. The teacher needs to develop her ability to ask questions which intensify the child's interest and involvement in the work he is doing. Questions which the teacher asks will not suddenly be transformed into an individual who can operate on the fourth level by the act of signing her first teaching contract.

Irrespective of the quality or lack of it in the teacher's pre-service preparation, there will be extensive need for in-service help and guidance to the teacher. The primary responsibility for guiding this in-service

development must rest with the principal who is and/or should be the instructional leader of the school. Availing himself of the services of the science specialist (if available), the principal must encourage and help his staff to keep abreast of the new developments in elementary curriculum and instruction. He should encourage and support the trial of new ideas in his school. Furthermore, he himself should be actively involved in the curriculum experimentation and research. Only through such involvement can he develop and reinforce the understanding necessary to exert leadership in this aspect of the educational program. Teachers interested in experimenting with the output of one or more of the curriculum projects should be encouraged by the provision of the necessary time, money and facilities. Most important, however, the administrator should develop a climate for experimentation where the teacher sees himself as a valued member of a team concerned with the overall improvement of the instructional program.

MINNEMAST: THE MINNESOTA MATHEMATICS AND SCIENCE TEACHING PROJECT*

MINNEMAST

MINNEMAST, the Minneapolis Mathematics and Science Teaching Project, is a National Science Foundation supported curriculum project for mathematics and science in the elementary school. In this program, children are encouraged to examine the intimate relationship between science and mathematics. The emphasis is placed upon the activities of the scientist. Sequential units have been developed in mathematics and science based upon the key operations of science. The MINNEMAST science curriculum has a spiral structure that is based on these key operations of science rather than on the customary science topics.

The Minnesota Mathematics and Science Teaching Project (MINNEMAST) is a long-range curriculum project for the purposes of coordinating mathematics and science, determining what children can learn, producing

* REPRINTED FROM the MINNEMAST publications *Questions and Answers about MINNEMAST*, August 1968, pp. 1-12, and *Overview*, July 1968, pp. 10 and 36. Reprinted by permission of the publisher.

and testing appropriate instructional materials, and preparing teachers to use these new materials effectively. The Project is supported by a grant from the National Science Foundation to the University of Minnesota. The director of the project is Dr. James H. Wertz, Jr., associate professor of physics.

MINNEMAST is the only project developing a coordinated mathematics and science curriculum—a program in which the science and mathematics curricula are sound in themselves and the interrelationships between the two subjects are exploited. This is in accord with the recommendations of the Cambridge Conference and of the American Association for the Advancement of Science.

Psychologists know that children learn much more when they are presented with related concepts in fields of study rather than with many isolated facts. MINNEMAST materials unify subjects that traditionally have been taught separately. Emphasis is on the many relationships among arithmetic, algebra, geometry, the biological and physical sciences.

Today we live in a world which is changing more rapidly than at any previous time in history. It is impossible to predict accurately what children will need to know. It has become imperative, then, that we give children the tools for lifelong learning, and equip them to solve problems as they arise.

In the past, teaching often has concentrated on memorizing facts, very few of which are retained. Our belief is that the students should be trained in the processes of mathematical and scientific thinking. The natural unification of mathematics and science makes it possible for the children to progress gradually from simple to more difficult mathematical and scientific operations.

The emphasis in the MINNEMAST program is on providing children with activities that help them solve problems using both mathematical and scientific techniques. The activities are also designed to encourage recognition of new problems which require experimentation and investigation.

MINNEMAST materials are oriented toward the child rather than the teacher. Traditional curricula are based on the idea of teaching children what it is felt they will need to know as adults. MINNEMAST aims at teaching the tools for life-long learning by emphasizing methods of acquiring knowledge rather than rote memorization of facts.

MINNEMAST is attempting to develop a coherent, systematic curriculum rather than separate units of instruction. Both the science and mathematics materials are sequential.

MINNEMAST science materials place special emphasis on observation, description, and measurement in the early grades, leading to meaningful experiences with inductive and deductive reasoning, hypothesis formation and experimentation in later grades.

MINNEMAST began on a small scale in the spring of 1961. In August

1962, the Project received a grant from the National Science Foundation to develop a coordinated mathematics and science curriculum.

Pilot work was done for several years before that under the auspices of the Minnesota State Department of Education through two organizational branches that were launched in 1958 by grants from the Louis W. and Maud Hill Family Foundation of St. Paul, Minnesota. The two branches were the Minnesota National Laboratory and the Minnesota Mathematics and Science Center. The latter has continued as the administrative base of the MINNEMAST Project.

The main ideas for a coordinated math and science curriculum had been outlined in an address by Dr. Paul C. Rosenbloom at a symposium of the Frontiers of Science Foundation of Oklahoma in December 1959. In 1962, MINNEMAST expanded to include a science curriculum and courses for pre-service teacher education. The Project has continued under grants from the National Science Foundation to the University of Minnesota.

One important concept threads through the curriculum, leading from observing objects to studying systems. Related threads introduce the important ideas of interaction and invariance.

MINNEMAST attempts to teach science as a coherent structure, rather than as a set of facts and skills, by:

Emphasizing the ways a scientist acquires knowledge, rather than focusing on knowledge as a finished product.

Leading the child to behave as a scientist—by observing, classifying, measuring, generalizing, predicting, and experimenting.

Teaching the child how to recognize problems and discover answers by means of his own activities, rather than the teacher's.

MINNEMAST mathematics materials emphasize two main mathematical structures. These are the real number system and the geometry of space.

In the early elementary grades the work centers on those areas where mathematics and science are closely allied, and also where arithmetic, algebra, and geometry are related. The children become familiar with algebraic language and with simple mathematical and scientific symbolism very early. Measuring is often used as an essential link between science and mathematics.

In KINDERGARTEN the children are introduced to a way of looking at the world around them. They are encouraged to watch and to wonder about it. Their observations include that of symmetrical patterns.

They learn to classify objects according to properties they have observed and to make qualitative comparisons, such as greater than, less than, appears to be the same as, before, after. They learn that properties of members and number of members of sets remain the same even when the sets are rearranged.

Using the basic concept of one-to-one correspondence, the children first

learn to pair objects in one set with objects in another set, then with tally marks, and finally with number words.

In FIRST GRADE the children continue observing, describing and classifying objects by their properties. Many patterns of symmetry are explored. Their work with sets includes the concepts of intersection and union, and the set interpretation of addition and subtraction.

The number line is introduced. This model of the real number system will be used throughout the MINNEMAST program. The children work with a number line as they learn to make quantitative measurements of length, area, volume, and duration.

The children learn to use an addition slide rule working with numbers up to 100. They learn the place value system and add and subtract 2-digit numbers without "carrying" or "borrowing."

They work with spatial relations and describe locations in terms of frames of reference.

In SECOND GRADE the children investigate the world around them by experimenting with systems of interrelated objects or substances.

They work with numerals up to 999, with fractions and with negative numbers. In measuring length and weight, the children discover the advantages of using fractional units for greater accuracy. The children add and subtract 2- and 3-digit numbers, and learn to check their own results through approximation. They are introduced to graphing and they review place value notation.

Using several algorithms, the children learn to multiply, finding products of whole numbers up to 6×6 , and to divide small whole numbers. They work with parallel scaled number lines and locate points for some non-integral numbers. The children work with Cartesian products, and experiment with a circular multiplication slide rule.

The children learn to make and interpret scaled diagrams and models. They learn to measure and record on graphs some changes that occur in their environment, such as in plant growth and temperature variation. Some properties and uses of angles are introduced.

In THIRD GRADE the children will continue working with numbers, investigating their innate properties and their relations to geometry and measurement. In a unit on motion the connection between the slope of a line on a graph, speed, and multiplication will be explored. In other units science activities will provide further practice with basic arithmetic ideas and algorithms and extend the children's understanding of the real number system. Work with geography and projective geometry will bring out the invariance and transformation features of the function concept in mathematics.

Two units will involve many biological and earth-science activities in the context of the systems concept, and will develop simple graphical and mathematical skills in describing these natural systems. The observable properties of matter will be investigated in a unit involving work with

chemistry. This unit will also review symmetry through work with crystals. Finally, a series of pamphlets, which the children themselves may read, will provide interesting and exciting historical sketches of the lives and adventures of some famous mathematicians and scientists.

An important implication of the MINNEMAST Project is that the child's education is being brought up-to-date. Discoveries of new knowledge are being incorporated into the elementary school curriculum. Cantor, in the 1880's, showed that the concepts of set and one-to-one correspondence are fundamental to the understanding of arithmetic. Until recently these ideas were taught only in graduate school mathematics; today, these concepts are introduced in kindergarten. In MINNEMAST, we concentrate on measurement as a tool of science and an application of mathematics. Measurement is fundamental to an understanding of the world, and has been markedly absent from earlier curricula.

The MINNEMAST staff works year-round, writing, teaching, testing, and evaluating materials. Also, for the past six summers, mathematicians, scientists, psychologists, and elementary and secondary school teachers from many parts of the country have met at the University of Minnesota to revise and extend the existing materials. Experimental classes are conducted concurrently with the writing project, providing a first-hand check on the appropriateness of the materials under development.

Writing teams of mathematicians and scientists—working with teachers and psychologists—plan the curriculum content, coordinating mathematics and science. They investigate the appropriateness of different materials and try to find the best examples that present math and science logically and sequentially, while using each to reinforce the other.

Elementary and secondary school teachers work along with the scholars in designing, writing, and testing the curriculum. This working relationship between teachers and scholars is one of the most important aspects of the Project. MINNEMAST believes that no curriculum project will really be effective until the curriculum developers can work hand in hand with the school personnel.

The work done by the psychologists is another very important aspect of the Project. The psychologists provide consultation to the writers, drawing on information from the fields of learning theory, child development and social psychology. They test and evaluate the materials with children to determine what has been learned, and offer their evaluations to the writers to be used in revising the materials. In addition, they make sure that the completed materials include appropriate tests for use by teachers in the classroom.

Even without a strong math and science background a teacher can use MINNEMAST. The in-service training and summer workshops provide excellent opportunities for teachers to work with scientists, mathematicians, and other educators—to learn how to teach good mathematics and science curricula.

MINNEMAST presents mathematics and science as creative arts. Children are given the experience of discovering the underlying laws of math and science. The Project attempts to instill in children the intrinsic rewards of learning. Children enjoy working with their classmates and teacher in experimenting, predicting, and discovering answers to their questions.

MINNEMAST materials have been used in two schools classified as being in disadvantaged areas in Omaha. The director of the center there reports that the materials have been remarkably successful. The children in these schools lack experiences and verbal skills, and the progress through these units therefore is sometimes slower than with other children. The children and teachers are very enthusiastic about the program, and the children have been able to grasp the concepts without too much difficulty. In situations where teachers have previously taught MINNEMAST units, the director reports that progress and success with materials is as good as that found in the suburban schools.

MINNEMAST materials attempt to provide for individual differences among children. Teachers have found that many children who have been labeled as "low-ability" students are not lacking in ability, but lack motivation. The materials attempt to motivate children by involving them in the lessons and activities. Evidence shows that children find the discovery method of learning much more exciting than anything else they do in school.

At the present time, there are over 20 affiliated MINNEMAST Centers, and approximately 60 schools using MINNEMAST units. During the 1967-68 school year, about 20,000 elementary school children in 600 classes were trying out MINNEMAST units. Approximately 5,000 new students were enrolled, of whom 3,000 were kindergarteners and 2,000 were first-graders.

A school system can acquire MINNEMAST materials and information about the Project directly from the Twin Cities Center. It is recommended that a school obtain assistance in using the materials from a MINNEMAST-affiliated university or college. There are several affiliated Centers throughout the country. These Centers can provide in-service training and workshops for teachers using MINNEMAST units.

For the 1968-69 school year, MINNEMAST materials available for experimental use will be:

Coordinated mathematics and science units for kindergarten, grade 1, and grade 2.

Separate mathematics units for grades 3, 4, and 5.

Separate science units for grade 3.

Coordinated units for grade 3 will be available for the 1969-70 school year.

The MINNEMAST Project has always looked forward to creating a coordinated K-6 curriculum in science and mathematics. Recently, the National Science Foundation has decided to curtail our efforts. Therefore, we have chosen to terminate the curriculum at grade 3, and to devote our full energies at MINNEMAST to the completion of the second- and third-grade materials and to the strengthening of the entire K-3 package.

Since third grade is now the final grade for the MINNEMAST curriculum, an effort will be made to reach a convenient pause in the progression of certain subjects in science and mathematics. We will avoid initiating work whose reinforcement in the higher elementary grades we cannot control. We will also attempt to find the best route to provide a smooth transition from the third grade of MINNEMAST to other upper elementary materials.

COPES: THE CONCEPTUALLY ORIENTED PROGRAM IN ELEMENTARY SCIENCE*

COPES

The Conceptually Oriented Program in Elementary Science (COPES) is supported by the U.S. Office of Education. Its purpose is to develop an elementary science curriculum which is centered on certain of the major conceptual schemes in science. The ultimate goal of the program is to develop an understanding of the nature of matter at various levels of sophistication, beginning at the time the children first enter school and continuing in a spiral development as far as the children's maturity and learning capacity will allow.

COPES is a science curriculum development project for kindergarten through sixth grade centered on certain of the major conceptual schemes

* REPRINTED FROM the COPES publication *COPES - Conceptually Oriented Program in Elementary Science*, March 1969, pp. 2-14. Reprinted by permission of the publisher.

in science.¹ The project is a logical extension of a successful pilot study² that investigated the feasibility of this approach by developing and testing materials for a sequence devoted to a single conceptual scheme that pervades all of science—the principle of energy conservation. This approach will now be broadened into a full-scale elementary science curriculum centered on five interrelated conceptual schemes.

THE PROBLEM

We accept the premise that general education in science is a necessary part of the educational structure, not so much for whatever practical values it may afford as for its pure intellectual stimulation and enjoyment. There is a growing awareness among the general public of the ever increasing impact of science and technology on modern civilization. Yet paradoxically our society is very poorly informed in science. The educated adult population holds the most naïve views of the natural world and of the scientific enterprise. Moreover, while admitting the dominant role of science in modern life, formal exposure to it is shunned by most of our citizens, some of whom display their ignorance of science almost as a badge of honor.

Thus, if one of the goals of science education is to help develop in the individual a grasp of the nature of the scientific enterprise, it follows that at present such education, for the most part, fails to achieve its purpose. Science belongs with those disciplines that traditionally have been regarded as essential to man's cultural enrichment; yet the average person fails to see it in this light. Perhaps the reason is that, unlike history or literature, the natural world cannot be described in a casual manner, and, unlike music or art, science cannot be enjoyed without understanding. But whatever the reason, clearly our educational system is at fault. It is likely that past efforts to minimize the intellectual challenge in science curricula have succeeded only in distorting the nature of the enterprise in the minds of most school children. By the time these youngsters reach high school, their natural curiosity and interest in science appear to be greatly diminished, and when they enter college most are actually repelled by science.

¹ Morris H. Shamos, "The Role of Major Conceptual Schemes in Science Education," *The Science Teacher*, XXXIII, No. 1 (January 1966), 27-30. *Theory into Action in Science Curriculum Development* (Washington, D.C.: The National Science Teachers Association, 1964).

² Morris H. Shamos and J. Darrell Barnard, *A Pilot Project to Develop an Elementary Science Sequence*, United States Office of Education Project No. H-281 (New York: New York University, 1967).

RATIONALE FOR THE CONCEPTUAL SCHEMES APPROACH

Granted the premise that some understanding of science is important for everyone, the question then follows, "What is the best way to help students attain a level of understanding and appreciation of the scientific enterprise that will serve them through their adult lives?" Our answer is to focus their attention on the "great ideas" in science, the broad, inclusive conceptual schemes in terms of which we seek to account for the familiar facts of nature. Such unifying ideas as the kinetic-molecular theory, the statistical view of the universe, the conservation principles, the gene theory of heredity, and so on, are the main goals of science and we believe should form the core of a science curriculum. They represent the pinnacle of explanation in science and must surely be classed among man's greatest intellectual achievements.

The use of conceptual schemes in science education is not new, of course. But it seems that for the most part these substantive ideas have been submerged in a morass of detail or overshadowed by undue emphasis on natural history and technology. Our approach is to stress the great conceptual schemes, to place them uppermost in the minds of the students and to relate all else in science, wherever possible, to these central ideas. We believe that such an approach may have genuine survival value, that long after he has forgotten the facts of science an individual exposed to such a curriculum may at least possess the main conceptual schemes and retain some feeling for the nature of the scientific enterprise.

There is another aspect to the conceptual schemes approach that we think is important, that is, to start such a curriculum as early as possible, preferably at the time a youngster first enters school. There is a growing conviction among many scientists and educators that it is in the elementary grades that the greatest impact can be made in science education. It is apparent that much more can be accomplished at this level than was believed possible in the past; the motivation and ability of children in the primary grades to deal with scientific concepts appear to have been grossly underestimated. It is also believed that many youngsters will have developed their patterns of thinking by the age of twelve. In these formative years, when minds are so receptive to new ideas, we believe it should be possible to develop a foundation in science that will remain a permanent part of the individual's intellectual life.

Within the last decade, several major projects have been initiated to develop elementary science materials. We believe that what is still lacking is a curriculum that shows promise of achieving the above goals. This is the primary purpose of the COPES program.

THE COPES PROGRAM

The ultimate goal of the COPES program is to develop an understanding of the nature of matter at various levels of sophistication. In the study of "the nature of matter" we include the entire breadth of science (both animate and inanimate)—an understanding of the structure of matter as well as its behavior.

We believe that having such a definite objective adds to the strength of a science curriculum, for it not only provides teachers and students with a clearly defined goal but also, perhaps more importantly, gives them a cohesive picture of science rather than a series of disjointed topics.

Each concept, each conceptual scheme in this approach, will be presented in a structured learning sequence with the purpose of contributing to this understanding. The order of the sequence will be in the form of a "spiral" development, in which, at each succeeding level of sophistication, the students proceed from the most basic skills and concepts through the entire sequence as far as their maturity and learning capacity permit them to go in understanding the major conceptual schemes or those concepts necessary to this understanding.

We propose to use this approach with children from the time of their entrance into school. Presently, the production of a science curriculum from grades K to 6 would appear to be the first task, since the K-6 level represents the beginning of formal education and generally forms a single administrative unit that is more flexible than other segments of the academic structure and more amenable to innovation.

This is an ambitious and necessarily rigorous undertaking. One must first identify the conceptual schemes that will form the basis for such a curriculum. There then follows a weeding-out process, after which are left only the major and supporting concepts directly relevant to the broader schemes. Finally, one must work back to find the best sequence(s) in terms of the skills and knowledge necessary and in terms of children's psychological readiness to accept relevant and peripheral skills, ideas and their interrelationships. And one must try to identify the educative processes that lead most directly to this learning.

THE CONCEPTUAL SCHEMES

Which conceptual schemes—which of the "great ideas" in science—should form the core of a conceptually oriented program in elementary science? There is probably no single choice of schemes that would fully express the views of all scientists and science educators. The breadth of the fields of interest and of science itself probably would result in many similar but not identical lists. After reviewing the efforts of two NSTA curriculum committees and following consultations with scientists and science educators, we have selected five conceptual schemes around which

the COPES curriculum will be developed. The selection was based both upon what the scientists felt would be a meaningful and durable science program and upon the successful development of a logical and rational hierarchy of concepts for the first conceptual scheme, conservation of energy—rational because its structure is based not only on the sequential growth of ideas but also on the abilities of children to think in terms of abstractions as well as of concrete situations, to do model building or to exercise the required manipulative or mathematical skills.

A limitation of the pilot study was the attempt to develop one conceptual scheme (conservation of energy) in isolation from others. This was obviously less than ideal since science cannot be so rigidly segmented. In the full program this will no longer constitute a problem since all the schemes are to be developed concurrently and suitably interwoven with one another.

Following are the five conceptual schemes on which the full COPES curriculum will be based, with a brief description of each.

1. The Structural Units of the Universe

The notion that the universe is made up of various kinds of discrete units of matter is central to the formal pursuit of science. Whether these be the smallest subnuclear particles or the largest stars, whether a single living cell or a complex organism, it is the discreteness of matter that makes it feasible to study nature—to classify its structural units and establish a hierarchy among them. The structural units with which students have any direct experience, that is, large-scale matter, are composed of smaller units and these, in turn, of still smaller units. Atoms, molecules, crystals, cells, organisms, plants, animals, planets, stars, etc., these are the structural forms in which matter is found. The more complex forms, or higher levels of organization, exhibit properties that are generally more than the simple sum of their parts. As for the fundamental "building blocks" of matter, for the purpose of the COPES program these are taken to be atoms or, as more commonly encountered in nature, molecules.

2. Interaction and Change

Taken as a whole, the universe is constantly changing. This is evident at most levels of organization—stars, planets, geological formations, living things, etc., all change with time in perceptible ways. Some changes are readily observable, which means that they occur in relatively short periods of time. Certain chemical and nuclear reactions are examples of rapid changes. Others, such as most evolutionary or geological changes, involving very long periods of time, are not as evident and must be inferred from indirect evidence rather than from direct observation. Thus, the rate at which a given change occurs is a critical factor in detecting this change and assessing its magnitude and import.

Changes occur because of interactions among the structural units of matter, with the result that either the properties or arrangement of the units may be altered. Interactions among units of matter take place through fields of force, of which several basically different types can be distinguished but only two of these, gravity and electromagnetism (electric and magnetic forces), are normally experienced by the average individual. In fact, the electric force alone is sufficient to account for most of our experiences, including practically all chemical and biological changes.

The weakest force (gravitational) and the strongest (nuclear) play particularly interesting roles in effecting changes in the universe. The former is significant only for the largest structural units (planets, stars, etc.), while the latter applies only to the smallest (subnuclear) particles.

Thus the concept of force (interaction) as the "agent" of change plays a central role in science and in understanding the evolving universe.

3. The Conservation of Energy

As one contemplates the concept of a changing universe it is comforting to find some properties of the universe that appear to be invariant. Such invariant properties are said to be "conserved," and the statements describing them are generally referred to as the "conservation laws."

The most fundamental of these laws are conservation of electric charge and conservation of energy. The latter is of special interest because it is so basic to all of science, finding numerous examples in both the physical and biological sciences. On the other hand, conservation of matter, if thought of as conservation of mass, while a useful concept in ordinary (low-energy) phenomena, is not valid for high-energy interactions. Instead, the principle of conservation of energy has been broadened to include mass as a form of energy, leading to the conservation of matter-energy.

The notion that the total amount of matter and energy in the universe remains constant is obviously a powerful conceptual idea, perhaps the most useful guiding principle in all of science. The more limited idea of conservation of energy alone, while not so inclusive, is found to hold so well for the (low-energy) interactions normally encountered by students (e.g., in energy conversion) as to constitute a highly significant conceptual scheme at the level to which the COPES program is addressed.

4. The Degradation of Energy

Natural events tend to have a unidirectional character. That is, changes occur in such a way as to bring the universe closer to a final state in which it will have lost the ability to do any useful work. Thus, in the conversion of energy from one form to another, while the principle of energy conservation applies, part of the energy appears in a form that cannot be fully harnessed to do mechanical work. This form is heat energy, by which

is meant the (kinetic) energy of the assumed random motion of particles of matter.

The idea of particles moving at random is central to the kinetic-molecular theory, which has proved to be such an effective model for understanding gases, as well as the concepts of heat and temperature and the states of matter. In this sense degradation of energy means that every change in the universe occurs in such a way as to result in greater randomness; that is, matter tends to spread out or become less organized and energy to distribute itself more widely.

In more formal terms, the idea that changes occur in this fashion is expressed as the second law of thermodynamics. Thus, heat flows from a warmer to a colder body, but the reverse is not observed unless energy is supplied from an external source. The same general idea applies to all changes, e.g., even to those in living systems, which appear to result in higher states of organization. While the organism itself may become more ordered, it does so only at the expense of its environment, which becomes more disordered, the net result being an overall trend toward disorder (increased entropy), meaning that the total energy is degraded.

One cannot fully develop the idea of energy conservation in a meaningful way without also calling attention to the *direction* of energy changes, as embodied in the corollary conceptual scheme, degradation of energy.

5. *The Statistical View of Nature*

The modern view is that natural events can be predicted only on a statistical basis. Most of our experiences with nature involve large numbers, with the result that on the whole nature appears regular and predictable. Even the smallest sample of matter with which one normally comes into contact contains huge numbers of atoms or molecules, so large that one can readily predict the *average* behavior of the sample. This is analogous to a game of chance, where given a large number of events the overall outcome can be reliably predicted, although the result of a single event cannot be forecast. In fact, the same mathematical laws of probability that apply to games of chance appear to be successful in helping one predict the statistical behavior of natural phenomena.

When one studies individual or small numbers of events, the random character of natural phenomena becomes evident. Radioactivity is one such phenomenon where behavior can be predicted only on a statistical basis. Another is the transmission of genetic characteristics to successive generations of living things, as described by the Mendelian laws. Still another is the Brownian motion of small (microscopic) particles. Examples are limited, since randomness is apparent only when dealing with small numbers, which one does not often encounter in nature.

Yet the idea that on a submicroscopic level all phenomena are random, and that nature is predictable only by the play of large numbers, is

obviously a basic and important conceptual scheme. The challenge is to convince students that one can reasonably generalize to this conclusion from the few concrete examples that are available.

CONSERVATION OF ENERGY— THE PILOT SEQUENCE

How does one develop an understanding of this powerful conceptual idea among elementary school children? Energy itself is an abstract concept. There is no precise description of it except to say that the change in energy of a system is a measure of the physical work done on or by that system. Nevertheless, we wish to convince young children that the total energy of the universe remains constant, that is, in any given process the energy is conserved in one form or another. If one considers mechanical energy alone, it is not very easy to be convinced of this; for instance, a bouncing ball never returns to the same height. It is only when heat is considered as a form of energy that the conservation idea becomes at all plausible.

The accompanying scope and sequence chart outlines the logical development of ideas and experiences used in the COPES approach to the conservation of energy. Grade levels at which a particular section of activities was found to be most appropriate are indicated on the left. The title of each section indicates the principal focus of its learning activities. At the K-6 level, two main threads in the conservation of energy sequence appeared most adaptable to the overall scheme—that is, conservation of thermal (heat) energy and conservation of mechanical energy eventually followed by the interconversion of these two forms. The rationale for the order of the sequence depends first on the selection of activities that provide the best and most meaningful (to children) examples of conservation of thermal and mechanical energy. The total structure of the sequence then reflects those major and supporting concepts and skills needed to cope with and fully understand the culminating activities. Before entering the major threads of the sequence, K-2 children would have had experience with activities designed to develop those skills and concepts needed for developing the major ideas starting at section D. We envisage that the broad base of K-2, so-called “presequence,” activities will serve as the foundation for all five conceptual schemes.

As the sequence proceeds from one major “conservation” activity to another, additional concepts are developed to provide a logical “lead-in” to the higher order, more sophisticated concepts. The classical example of conservation, the Galilean pendulum, was considered as one of the final activities toward which the sequence would be aimed. Originally it was believed that since children enjoy pushing and pulling objects, this might be an appropriate avenue of approach to developing the idea of

conservation of energy. Although the concept of force can be adequately developed, the concept of work or mechanical energy appears much too abstract for the young child in the early stages of the sequence.

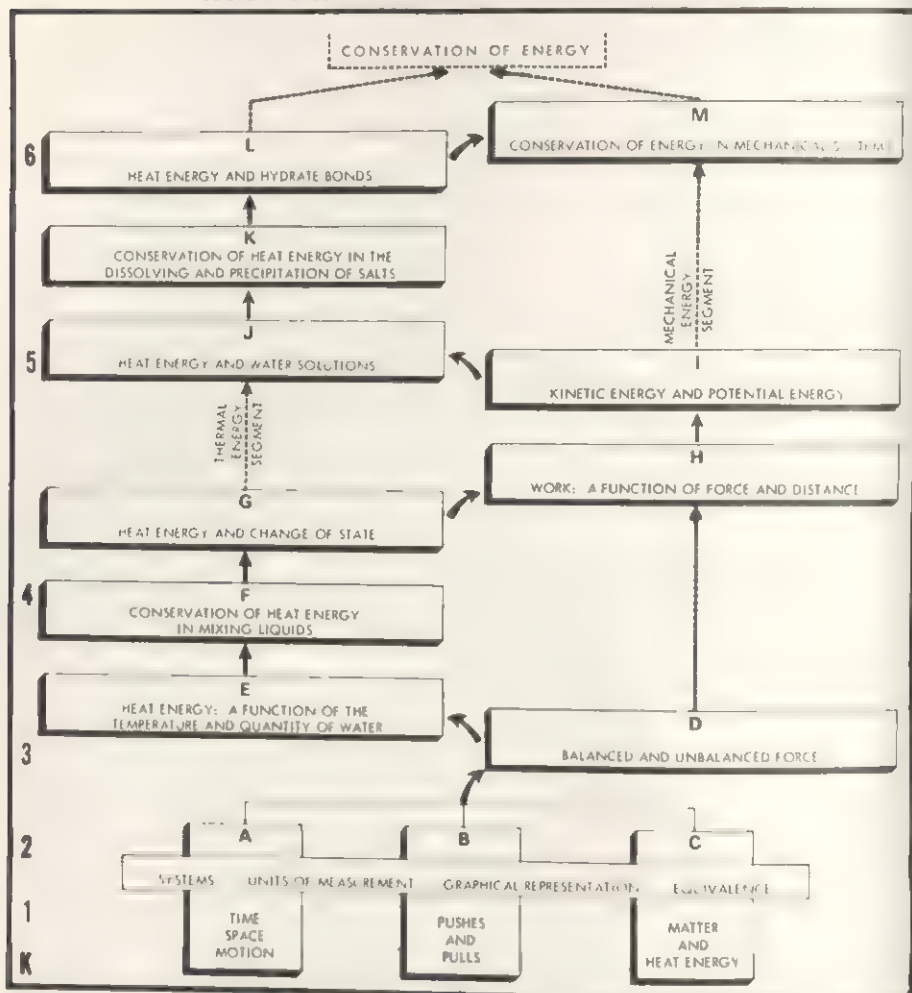
It was found, however, that the concept of thermal (heat) energy has more meaning for the young child, hence it was decided to begin the sequence by developing activities focused on conservation of thermal energy rather than mechanical energy. Three major examples confirming conservation of thermal energy were used because they were felt to be meaningful at the K-6 level. In hierarchical order they are (1) heat energy is conserved when samples of a liquid are mixed (section F); (2) the heat energy absorbed to dissolve a salt in water will be released when the salt precipitates (section K); and (3) the heat energy required to break the bonds of hydration will be released when the bonds reform (section L). The intermediate sections of the thermal energy thread must then provide the bridging concepts. For instance, before working with concepts of solution, the idea of the difference in energy between the liquid state and its solid has to be considered. Thus, a section of activities is devoted to the relationship between heat energy and change of state. When pursuing activities in section F, where the temperature of a mixture of water samples can be accurately predicted on the assumption that heat energy is conserved, the child must first develop the concept that the heat energy in a sample of matter (liquid water, for example) depends not only on its temperature but also on its quantity.

Similarly, the structure of the mechanical energy thread is determined by the more elementary concepts needed to appreciate the conservation of energy in a swinging pendulum. Starting with simple concepts of force, leading into the concept of work, the more abstract concept of the energy of moving bodies (kinetic energy) is then developed. This is followed by the concept of potential energy as measured by the work done on an object or the "potential work" the object can do. The child is then ready to analyze the energy relationships in the pendulum, an almost ideal machine. Since he has been accounting for heat energy in the thermal thread, he again attempts to account for the small "losses" of mechanical energy in the pendulum. His familiarity with heat energy can be used to develop the concept of conversion of mechanical energy to heat by friction as the source of the "loss." Thus, energy in the system apparently has been conserved. His search for an explanation of the losses helps the child to develop a feeling for, and confidence in, this great conceptual scheme—conservation of energy.

THE COPES CURRICULUM

The full COPES curriculum will be a structured program, with the concepts organized in a logical hierarchy. All five of the conceptual

SCOPE AND SEQUENCE CHART: CONSERVATION OF ENERGY



schemes will be developed concurrently. Positioning of a concept within a particular scheme will be determined on the following bases: its contribution as an introductory idea, its suitability for active exploration at a given age level and its relative sophistication as a component of the scheme.

It is anticipated that the K-2 portion of the curriculum will be composed of sets of introductory concepts contributing to an understanding of such topics as: Pushes and Pulls, Time-Space-Motion, Matter, Energy and Randomness. There is no intention of treating any topic at one grade level only. Rather, increasingly sophisticated activities related to each topic will be included in the sequence for each of these three years.

For example, *Melting—A Change of State*, is designed as a kindergarten activity to build introductory concepts concerning matter. This is followed by studying *When Solids Dissolve* in the first grade and *A Close Look at Crystals* in the second grade.

Those concepts intended to develop the five conceptual schemes will be spread through grades 3-6. In some instances, a concept will be related almost exclusively to a single conceptual scheme, but many concepts will be related to two or more schemes. As in the case of the sets of introductory concepts, no one scheme will be designated for teaching at any one grade level. Rather, it is anticipated that children will be learning concepts related to each of the five conceptual schemes in every one of the four upper grades. The conservation of energy pilot sequence described earlier illustrates the continuous development of concepts related to one of the conceptual schemes.

The COPEs curriculum is action centered. Almost all activities will require that explorations of a nonreading nature be carried out by individuals or by small groups of students. For this reason, there will be opportunity for continuous development in grades K-6 of such skills as estimating, experimenting, interpreting, measuring, observing, ordering, predicting and recording. We believe that such active exploration on the part of children is imperative if they are to learn, rather than memorize, concepts selected to build faith in the conceptual schemes of science.

THE PILOT STUDY

As mentioned earlier, the feasibility of a conceptual schemes approach was tested in a two-year pilot study. Scientists, science educators, elementary science specialists, psychologists, teachers and elementary school children were involved. Teaching materials dealing with concepts related to the idea of conservation of energy were developed. Based on evidence obtained from tryouts with children in COPEs laboratory schools, the activities were revised and arranged into a K-6 teaching sequence following the structure shown in the chart on page 11. A guide for teaching the sequence was prepared.³

The teaching materials for the conservation of energy were then tested in two elementary schools in Great Neck, N.Y. Two elementary science specialists taught the materials to children in one experimental group of classes ranging from kindergarten through grade 6 in each of the schools. Each class in the experimental group proceeded through the sequence of materials as far as the children were capable of handling the skills and concepts involved. Children in one sixth-grade class completed the entire sequence.

³ *The Teacher's Guide for a Conservation of Energy Sequence*, COPEs Project (New York: New York University, August 1967).

Tests designed to measure understanding of concepts in the sequence were used in assessing the achievement of children from grade level to grade level. The tests were also used to compare achievement of children in the experimental groups with achievement of children in corresponding control groups in each school. The teaching materials were evaluated by the specialists who used them in teaching the children and by the regular teacher in each class who observed the teaching.

The overall outcome of the pilot study was highly positive.⁴ The evidence clearly demonstrated that a conceptual schemes approach to elementary science is entirely feasible. Classroom observations and test results revealed that children at successive grade levels were able to attain progressively sophisticated concepts leading toward an eventual understanding of the conservation principle.

⁴ Shamos and Barnard, *op. cit.*

THE SCIENCE MANPOWER PROJECT'S ELEMENTARY SCIENCE PROGRAM*

Frederick L. Fitzpatrick and Willard J. Jacobson

This article is part of a longer article which presents the complete K 12 science program of the Science Manpower Project. In this article the authors describe in detail (1) the five major goals of the K-12 program, (2) the five important characteristics of the K-12 program, and (3) the two dimensions—flexible and planned—of the elementary science program. The authors believe that the Science Manpower Project was one of the forces that led to change and improvement in American science education.

As early as 1953 officials of Teachers College, Columbia University, pointed out that the elementary and secondary school science programs of various school systems were sadly deficient, and that insufficient numbers

* REPRINTED FROM "The Science Manpower Project: Its History and Its Program," *Science Education*, Vol. 52, No. 3, April 1968, pp. 256-257, 260-265, 269. Reprinted by permission of the authors and the publisher. Dr. Fitzpatrick is Professor Emeritus of Education and Dr. Jacobson is Chairman of the Department of Science Education at Teachers College, Columbia University.

of scientists and engineers were being educated to meet the needs of the national economy. At this time enrollments in the high-school sciences, and particularly in the physical sciences, had reached a low ebb.

Planning for a Science Manpower Project was begun in 1954. The Science Manpower Project was dedicated to the improvement of science education in the nation's schools, and the cultivation of student interest in science and science-related careers. *Associates* in representative teacher-training institutions across the land were selected, and rotating groups of *Fellows* were recruited to work at Teachers College, Columbia University. Support for the Project was obtained from leading American industries and foundations, and operations began in September, 1956.

GOALS

The project was scheduled for an active existence of five years. This period was to be devoted to fact finding, the writing of policy report and recommendations, and the preparation of various curriculum materials for use in planning science education programs. The initial goals were

1. To clarify the nature of the problems involved in improving science education.
2. To exert an influence upon the public and the schools and to arouse interest in the improvement of science programs.
3. To provide guides for the improvement of instructional programs.
4. To foster changes in teacher education designed to produce a larger and more effective corps of science teachers.

Due to public concern about Soviet advances in science and technology, the need to implement the second of these goals was soon minimized. Meanwhile, continuous pressure from schools that were hastening to revise and modernize their science offerings served to concentrate effort upon the third goal, somewhat at the expense of new designs for teacher education. But as modified by events of the times, the activities of the project operated on schedule, and when the five year period ended, the materials planned for production had been made available to the schools.

THE K-12 SCIENCE PROGRAM

In the past few decades the importance of science and technology in our individual lives and in our society has increased markedly. We may hope that the educated man of the future will have some understanding of the important generalizations of science, just as we have always expected him to have some acquaintance with the literature, music, and art of his

culture. In addition, we all use the fruits of science and technology in our daily lives. In fact, a growing proportion of our population functions in scientific occupations and professions.

The importance of the scientific enterprise in modern life places new demands upon our schools. On the one hand, the schools have a key role in educating the scientists and technologists of the future—a future in which a continuing population increase seems highly probable, and expansion of the national economy is anticipated. In this context, the schools must prepare citizens who have enough understanding of science and technology to make sensible decisions about a multitude of problems in which science and technology provide keys to solutions.

To prepare scientifically literate citizens and, at the same time, meet scientific manpower needs required planning. Too often in the past the science experiences of elementary schools, junior high schools, and senior high schools have been planned without reference to “what the other fellow is doing.” Unfortunately, this leads to tiresome repetition of relatively simple concepts at successive levels of instruction and generally ineffective programs. This can be avoided if science sequences are planned on a K-12 basis.

In fact, the development of K-12 science programs is one of the most challenging tasks of the science educator. Such programs are not conceived of as being uniform throughout the land, although they must necessarily have various common elements. In some way or another, they must deal with the important aspects of science including the new as well as the traditional. They must be devoid of interest-deadening repetition, but at the same time help young people build upon their previous science experiences. The K-12 sequence designed by the Science Manpower Project represented a sort of template, which could serve as a basis for the development of appropriate programs at the local level.

At this point it is appropriate to note that teachers and curriculum planners must have some concept of the directions in which they hope that pupils and students will develop. Moreover, statements of goals should have operational meanings; i.e., they should have meanings in terms of our day-to-day work in teaching science. The following were among the goals of the Science Manpower Project’s K-12 science program, with concrete examples that gave them operational significance:

1. *To develop a better understanding of the physical world.* This has always been one of the most important objectives of science teaching. We want our youngsters to possess an adequate *weltanschauung*: a reasonably complete picture of the world in which they live, and a rational idea of their place in this world. This goal becomes critically important in this age when our knowledge of the world appears to be increasing geometrically. We live in a vast universe; recognition of this vastness has challenged our imaginations and opened new vistas for exploration. The development of a view of our world which is consistent with the evidences emerging in a

wide range of sciences is essential for optimum growth and development.

2. *To help young people gain some understanding of the methods and processes used in the sciences.* This category is really a continuation and elaboration of some of the elements in No. 1. Methods used in the sciences are among the most powerful intellectual tools man has developed, and some of these methods can be used to deal with questions and problems that students recognize. In the scientific approach, suggested answers or proposals for action are subjected to empirical, experimental tests.

As young people engage in various kinds of science activities, it is extremely important that they be made cognizant of the methods employed.

3. *To learn more about their bodies and how to take care of them.* Knowledge about the human body has been developed in such subsiences as physiology, pathology, immunology, chemotherapy, and nutrition. Average life expectancy has been increased about 20 years in the last half century. However, health is more than the mere absence of disease. It is a state in which each individual can operate at his optimum effectiveness. Few individuals attain this highly desirable state. Through the study of the human body and how to care for it, students can come closer to achieving this goal. The study of the human body and how it works is especially important for the early adolescent, for he is at a stage when profound, and to him mystifying, changes are taking place in his body.

Many students have studied the effects of various kinds of diets upon growth and development. These studies are usually made with white rats. The laboratory rat has various nutritional requirements that are similar to those of humans, and effects of nutritional deprivation appear relatively soon in the case of the rats. Studies usually take the form of controlled experiments, in which some rats are given an adequate diet, while other rats subsist on a diet deficient in some nutrient. Students learn how to set up a controlled experiment, make observations, secure and record data, interpret data, and perhaps discover that "what you eat makes a difference."

4. *To learn what it is like to work and study in science.* Guidance has always been an important dimension of the junior high school program. Much basic work should be done in such areas as science, industrial arts, social studies, mathematics, and English. As a part of this study students should begin to acquire an understanding of what it is like to work in occupations and professions related to science. They should also learn something about the kinds of preparation they will need for various occupations and professions. In the senior high school they will begin to make choices among subjects in the school program. Since basic courses in science and mathematics are often prerequisites to more advanced study, it is essential that students keep the doors to future opportunities open.

5. *To prepare for effective citizenship.* In our democracy, citizens and

their elected representatives have to make decisions concerning conservation of natural resources, agricultural policies, transportation, communication, atomic energy, public health, national defense, space explorations, industrial developments, air and water pollution, and education. Science and technology are involved in nearly all of the decisions, and if the decisions are to be intelligent, our citizens have to know something about the basic science and technology that is related to the various problems. For many future citizens, the K-12 science program provides the last opportunity for an organized study of the wide range of sciences. The responsibility for the future effectiveness of our democratic way of life that must be shouldered by teachers of science is indeed impressive.

Perhaps one of the best ways to prepare for effective citizenship is to have experience in studying, analyzing, and suggesting possible solutions for current community, regional, state, national, and international problems related to science and technology. In the Science Manpower Project's proposal, for example, problems of the conservation of biological resources are considered at the community level, problems related to energy sources at the regional level, and problems concerned with atomic energy at national and international levels. In considering these problems, methods of study and analysis are emphasized, for as time goes on, the nature of the problems will change, but it will always be helpful to seek pertinent information, to know how to use the findings of experts, and to give consideration to honest differences of opinion.

PROGRAM

A number of approaches might be followed in efforts to develop more effective school science programs, and this is significant in view of the fact that communities, student groups and teaching staffs vary in a multitude of ways. For reasons such as the foregoing, the program of studies sponsored by the Science Manpower Project has its greatest potential utility as a *guide to the establishment of science sequences at the local and state level*. But it is believed to have a number of important characteristics that should be represented in any program modeled upon it. These characteristics are as follows:

1. *A wide range of science content is included.* In recent decades our scientific knowledge has been expanded at a rapid rate. Much of the new knowledge is highly significant, and must be at least considered for inclusion in revised courses of study. It has become inconceivable to ignore the potential contribution of astronomy, astronautics, biochemistry, biophysics, immunology, oceanography, and meteorology.

2. *The recommended program is articulated.* So much challenging material is available for inclusion in science programs that repetition of various learning experiences at essentially the same level of difficulty is a practice to be avoided. Yet it is a practice that has characterized many

curriculums up to the present time. In the Science Manpower Project's proposal a broad spiral approach has been employed, so that a given area of knowledge is dealt with every third or fourth year, and in all cases an attempt is made to use a fresh approach at a more sophisticated level.

3. *Provision is made for study in depth.* Making more time available for science instruction at the lower levels of the school and eliminating repetition makes it possible to consider blocks of subject matter in greater depth than has previously been the case. There also is more time to consider scientific methods of study and analysis, and to employ the problem-solving approach.

4. *Important generalizations are emphasized.* The significant concepts, principles, and theories of science serve as guidelines in curriculum planning, and gaining an increasing understanding of them is one of the goals of instruction. At the same time, the interrelationships of the various sciences are considered, as well as the interrelationships of the scientific enterprise with non-science areas of knowledge.

5. *A variety of teaching methods is encouraged.* In teaching the K-12 program of the Science Manpower Project it is assumed that a variety of approaches to teaching will be employed. It is a case of using the methods and materials best suited to a particular objective, and taking into account the teacher's resources and the particular student group under instruction.

SCIENCE FOR THE ELEMENTARY SCHOOL

The Science Manpower Project's program for the elementary school has two dimensions: a *flexible dimension* and a *planned dimension*. In the former, pupils have many experiences that originate with their own questions, or with projects they undertake, or with community events. In the latter, however, there is an organized attempt to introduce the pupils to six broad areas of science. It is believed that the classroom teacher-science consultant team can provide this instruction most effectively, but it is a program that can be and is being taught by classroom teachers alone.

In setting forth their recommendations for the elementary science sequence Jacobson¹ and Tannenbaum² noted that certain criteria should be kept in mind in developing such a program. These criteria, in substance, are as follows:

1. The program should be consistent with our tested knowledge of child development.

2. The experiences should nurture pupils' natural curiosity or desire to

¹ Both the planned dimension and the flexible dimension.

² Jacobson, Willard J. and Tannenbaum, Harold F. *Modern Elementary School Science*. Teachers College Press, Teachers College, Columbia University, New York, 1961.

"find out." Questions and problems that children raise should be analyzed and studied.

3. There should be many opportunities for direct experiences with materials of the environment. Children should learn to handle apparatus and materials of science.

4. The elementary science program should be an integral part of the school's K-12 program. The elementary science program should be viewed as a base for the total school science program.

5. The physical, biological, and earth sciences should be represented in each year of the elementary science sequence, and modern developments in the newer sciences and subsiences should not be overlooked.

6. Needless repetition of learning experiences should be avoided. When a general area is dealt with a second time, the approach should be different, and should contribute to the development of more refined concepts.

7. The areas of science should be developed in depth, the major limitation being the previous experiences and maturity of the pupils.

8. Science activities should be planned so that children learn to use some of the procedures that are characteristic of science in dealing with questions and problems.

9. The experiences in science should be planned so that children learn to use some of the broad, pervasive generalizations of science to interpret events and phenomena of their environment.

10. The people who are to implement a science program must have opportunities to gain a clear understanding of the program, and should be involved in the actual planning of the program.

The Flexible Dimension

In this dimension of the program there is excellent opportunity to relate the instruction to the non-science areas of the curriculum. Similarly, there is provision to deal with the needs, interests, and concerns of the pupils, and to give attention to the ever-present problem of individual differences. Necessarily, this phase of the program is very likely to vary from year to year, and from one pupil group to another, and long-range planning can only be effective in rather general ways.

The Planned Dimension

Jacobson and Tannenbaum³ have provided rather detailed suggestions for the organization of this planned dimension of the elementary science program. In grades K-6 six blocks of subject matter are dealt with according to the following formula:

1. The earth on which we live
Study of rocks—grade 1

³ *Ibid.*, pp. 40-126.

- Study of soil—grade 2
- Study of weather and climate—grade 3
- Study of the earth's changing surface—grade 4
- History of the earth—grade 5
- The earth's resources—grade 6
- 2. Healthy living through science
 - Foods we should eat—grade 1
 - Preventing the spread of disease—grade 2
 - Our ears and hearing—grade 3
 - Our eyes and sight—grade 4
 - Good nutrition—grade 5
 - Community sanitation and health—grade 6
- 3. The earth in space
 - The earth and the sun—grade 1
 - Air and the atmosphere—grade 2
 - The sun and the planets—grade 3
 - Oceans and the hydrosphere—grade 4
 - Space exploration—grade 5
 - The Milky Way and beyond—grade 6
- 4. Machines, materials, and energy
 - Simple machines—grade 1
 - Heat and temperature—grade 2
 - Energy and energy sources—grade 3
 - Water and water supply—grade 4
 - Simple electronics—grade 5
 - Flight in air and in space—grade 6
- 5. The physical environment
 - Study of magnets—grade 1
 - Fire and fire protection—grade 2
 - Sound and music—grade 3
 - Light and photography—grade 4
 - Electricity—grade 5
 - The materials of our environment—grade 6
- 6. The biological environment
 - Animal life—grade 1
 - Plant life—grade 2
 - Living things and their environment—grade 3
 - Organization of living things—grade 4
 - Adaptations of living things—grade 5
 - Man's use of living things—grade 6

THE FUTURE

The Science Manpower Project monographs were designed as guides for curriculum revisions that are in turn effected by individual school systems. The extent to which the Science Manpower Project's activities have

influenced policy and curricula at local and state levels is difficult to estimate. The courses of study developed in several states and large city school systems have been designed along the lines suggested by the Science Manpower Project. Thousands of the monographs have come into the hands of superintendents, principals, curriculum supervisors, and science teachers. Initially, it was possible to provide complimentary copies to school administrators, but because of the large volume of requests, this is no longer possible.⁴ It is perhaps fair to suggest that the Science Manpower Project was one of the forces that led to change and improvement in American science education.

Much, of course, remains to be done. It is becoming clear that a major limiting factor in the further development of science programs is the teacher. The task of preparing high quality teachers in sufficient numbers for all levels of education has barely been faced and hardly begun. The new technology that may make a different kind of education possible has not yet been tapped to any appreciable extent. The hardware is there, but the programs await creative science educators who can undertake the gigantic task of preparing them. Also, insufficient attention has been given to the role of science in our society. There is a need for creative approaches to the development of policy and curricular programs that will help the next generation to use science more effectively in our changing society.

The task of improving science education is never-ending. There probably is no one best way to develop a science program. Instead, a variety of programs and approaches to teaching are needed. The Science Manpower Project was the result of an idea and a desire to do something. By today's standards the Project operated with relatively little support, and almost all of this support came from enlightened industrial firms and foundations. We hope there will continue to be room for variety in the attempts to improve science education, and that others who have an idea will seek support and try to transform that idea into action. Essentially, this is what the Science Manpower Project did.

⁴ Copies are still available, however, from the Teachers College Press, New York, New York, 10027 at modest cost.

ASTRONOMY FOR GRADES FIVE THROUGH EIGHT: UNIVERSITY OF ILLINOIS ELEMENTARY SCHOOL SCIENCE PROJECT*

Joann M. Stecher

The University of Illinois Elementary School Science Project is supported by the National Science Foundation. Its specific purpose is to produce astronomy materials that are sound astronomically, that reflect the structure of the subject as it is viewed by astronomers of stature, and that can be handled by teachers and children in actual classrooms. The prepared materials are designed for use in grades five through eight.

The University of Illinois Elementary School Science Project is an astronomy sequence for grades five through eight that delineates certain major concepts intended to assist the student to perceive the basic structure of the subject. By concentrating on the intellectual power of a few pervasive ideas in astronomy, a cogent entity is developed, rather than a description of loosely connected facts and phenomena. "Process" goals that characterize certain elementary-school science programs are also emphasized. In particular, project books stress the development of a rational argument for a scientific idea, rather than assertion.

During the summer of 1964, nineteen astronomers, science education specialists, and teachers participated in the fourth summer writing conference of the Project. A brief description of the six books written during these conferences illustrates the topics by which the unifying ideas of the astronomy sequence are presented.

Book 1, *Charting the Universe*, covers such topics as measurement, distances in the solar system and beyond, the size and shape of the earth, and the inverse square law applied to light as a tool for determining great distances. Book 2, *The Universe in Motion*, outlines conceptual models to account for observed motion. The student is introduced to geocentric and heliocentric perspectives. Book 3, *Gravitation*, deals with such concepts as

* REPRINTED FROM *Science and Children*, Vol. 2, No. 5, February 1965, pp. 23-24. Copyright, 1965, by the National Science Teachers Association, Washington, D.C. Reprinted by permission of the author and the publisher. Miss Stecher, now Mrs. Elzam, was Research Associate at the University of Illinois. She is presently associated with Prentice-Hall, Inc.

velocity, acceleration, mass, and force. The focus of Book 4, *The Message of Starlight*, is on methods astronomers use in analyzing starlight to obtain information about the composition of stars. The emphasis in Book 5, *The Life Story of a Star*, is stellar evolution. Book 6, *Galaxies and the Universe*, introduces the student to our galaxy, other galaxies, and cosmology. Astronomy is an outstanding instance of an interdisciplinary field in the physical sciences. Concepts of physics, mathematics, physical chemistry, and geophysics are essential features of each book.

The first three books have had extensive trial in schools all over the country. The classroom situations were in public and private schools; suburban and urban schools; segregated and nonsegregated classes. The teachers varied widely in science background. Science consultants, principals, or teachers served as local project coordinators and also gave assistance to individual teachers as needed.

Book revision has been based on the reactions solicited from cooperating teachers both in writing and through interviews. Members of the Project staff observe extensively in classes where the materials are being tried to supplement written teacher reactions. Numerous conferences are held with participating teachers. Judgments are also invited from scientists who have not participated in the summer writing conference.

The testing phase of Book 1, *Charting the Universe*, and Book 2, *The Universe in Motion*, and their teacher's guides have terminated. Enough data from teachers and consultants were accumulated to develop an edition of these books that will stand for the present. Book 3, *Gravitation*, was revised in 1964 on the basis of reactions from over 300 teachers who tested the materials during the 1963-64 school year. The teacher's guide for *Gravitation*; Book 4, *The Message of Starlight* and its guide, are now in trial edition form and are being tested in classrooms during 1964-65. Substantial preliminary writing has been completed on the remaining books in the series, but Books 5 and 6 will not be submitted for extensive classroom trial until 1965-66.

Certain evaluation activities have been initiated that extend beyond book revision. The Project is interested in certain long-range effects of the books on children—how their viewpoint of science and scientists may have been modified, for example.

The Project has been supported since 1960 by the National Science Foundation. Co-directors are J. Myron Atkin, Professor of Science Education, University of Illinois and Stanley P. Wyatt, Jr., Professor of Astronomy, University of Illinois. Senior authors for the series are Henry Albers, Astronomy Department, Vassar College (Book 1); Karlis Kaufmanis, Astronomy Department, University of Minnesota (Book 5); Benjamin F. Peery, Astronomy Department, Indiana University (Book 4); Gibson Reaves, Astronomy Department, University of Southern California (Book 6); and Stanley P. Wyatt, Jr. (Books 2 and 3).

THE IMPACT OF EXPERIMENTAL PROGRAMS ON ELEMENTARY SCHOOL SCIENCE*

Shirley A. Brehm

In this article Shirley A. Brehm describes some of the causes for the emergence of the several new experimental programs in elementary science. She points out that these programs have several features in common. The programs are experimental, emphasize process, evoke a new role for the teacher, give a new importance to the development of concomittant mathematic skills, introduce abstract concepts at an early level, emphasize children's activity, and emphasize science as a "skill" subject. Finally, Dr. Brehm discusses the impacts which these programs are making on the teaching of elementary science.

Elementary school personnel are experiencing an unusual situation today concerning curricular innovations. While a few years ago curriculum changes were developed primarily by teachers themselves, the curricular possibilities of the 1960's have evolved through the cooperative work of academic experts and highly qualified, select classroom teachers. It is general knowledge that elementary school science and mathematics have been experimented with more extensively than have other curricular areas in the elementary school. For the most part elementary science and mathematics curricula of this decade have been written, taught in sample classrooms, tested, re-written, taught again, and often revised again. Furthermore, the composition of the several groups working in the various writing conferences has been national in scope as opposed to either regional or local.

CAUSES FOR NEW PROGRAMS

The Influence of High School Revisions

To understand more fully the implications of the experimental

* REPRINTED FROM *Science Education*, Vol. 52, No. 3, April 1968, pp. 293-298. Reprinted by permission of the author and the publisher. Dr. Brehm is Associate Professor of Education at Michigan State University.

curricula, it is necessary to examine some of the causes for the emergence of the trial programs. One of the more prominent stimulators of experimental elementary curricula was the wide acceptance of science programs developed since 1955 for the high school age group. These can no longer be considered experimental today. The Biological Science Curriculum Study (BSCS), the Physical Science Study Committee (PSSC), the School Mathematics Study Group (MSG), to mention only a few, are well known examples of high school curricular developments. Innovators at the secondary school level became more and more concerned that students entering high school should have a better and a different type of background in science and mathematics than students had had previously. It was felt that the lower school preparation should not revolve around added quantity of science or mathematics per se, but it should reflect a deeper insight into the structure of the subject and the very method of inquiry unique to that subject. These innovators, who represented academic specialties in the sciences and education, began to investigate means of revising the elementary school programs. As a result several elementary curricular experiments grew in downward trend, while others began with kindergarten and grew upward.

Explosion of Knowledge

A second cause for the experimental work in elementary science and mathematics was the veritable explosion of knowledge resulting from, and contributing to, the scientific era we are experiencing. The older emphasis on the accumulation of factual knowledge for its own sake could no longer remain valid because of the plethora of this knowledge and the rapidity with which factual knowledge was outdated. It became evident that quantity alone would not do, but that a qualitative revision of the early work in science and mathematics was required. Unlike the weeding out process of the 1890-1910 era revision in elementary arithmetic in which complex and difficult "problems" were discarded, this present revolution in science and mathematics emphasized a shifting of focus away from social utility toward two closely related objectives: a comprehensive investigation of major ideas called the structure of discipline; and the ability to act as a scientist acts called the process of inquiry of the discipline.

New Advances in Learning Theory

Closely related to these were the concerns of cognitive psychologists [1] for how one learned best and retained best those things learned. Early indications from psychological studies emphasized the position taken by the experimental curriculum builders: one retains learning best if it follows a pattern—but this pattern or structure is unique to the subject matter and to the learner's way of structuring the subject. Another

psychological premise underscored the manner in which persons learned—the process of involvement. Interestingly enough, both of these ideas have been part of the stock-in-trade of highly competent teachers. While most teachers have tended to operate on an intuitive plane concerning either or both of these ideas, it has taken the learning psychologists to initiate the placement of the ideas into the more formal, logical pattern and thus enabling the educators to examine and implement these ideas more fully.

Speeding Up the "Grassroots" Process

A fourth factor in assessing the advent in elementary curricular innovations, oddly enough, was the very procedure used in developing curricular programs prior to the experiments of the 1960's. This writer recognizes the need to fully explore the pros and cons of teacher involvement in curriculum building, and admits a strong bias toward teacher involvement. Yet this article is neither the time nor the place for such an extended discussion. The point to be made here, however, is that despite the positive aspects inherent in a philosophy of grassroots curriculum development, the factor of social lag had become extremely significant. According to many persons involved with the rapid transformation of knowledge and ways of knowing, there was not time to permit a thorough realignment and education of all personnel in terms of content, psychology, educational methodology for individuals to become experts in each and every speciality. It followed that these tasks, then, could not remain the sole responsibility of school personnel, who may be competent in one specialty only—methodology, with secondary competencies in other areas such as content. More and more the fact had become evident that what was needed was a broadly based team approach with several specialists brought together to share solutions to common problems. The Woods Hole Conference [2] held in 1959 was a good example of this approach to problem-solving in curricular development.

However important the grassroots program was concerning curriculum development, it fostered a diversity that could be typified as unevenness in the emergence of sound programs. Furthermore, under the guise of grassroots curriculum, many schools left the elementary science program almost entirely to the interests of the individual teacher who may have had limited resources and interests to bring to bear in solving this problem. This resulted, often-times, in a fragmented, factually oriented program in elementary science, and a dull, routinized, mechanical operation in mathematics, with the textbook as the sole arbitrator of both methodology and content.

The Need to Keep in Touch with Emerging Knowledge

Where curriculum committees did exist in local school systems, these were composed almost exclusively of public school personnel—teachers,

administrators, consultants who themselves were not close enough to the emerging knowledge in the several disciplines. This is not meant to castigate curriculum committees for not including the scientific specialists earlier: these scientists and academic specialists had spurned any commitment they might have had to the broader field of public education for they were committed solely to their discipline. So the situation evolved wherein the public school curriculum committees tended to rework the older content of the curriculum and to emphasize the comfortable pattern of subject matter in elementary science based on the biological sciences for the most part, with some inclusion of the physical and earth sciences. The outcome of this situation was a heavy stress upon the acquisition of factual information.

Then, too, these same committees knew only too well the complex task faced by elementary teachers in the self-contained classroom as they implemented the many curricular areas: the subtle weaving together of experiences and concepts drawn from social studies, science and the skill involved in the language arts-mathematics spectrum into meaningful classroom learning experiences. The elementary classroom teacher typically has focused major attention on the development of the child, and in so doing she has utilized subject matter content as a vehicle for accomplishing this goal.

As a result of concerns more immediately connected with children in the elementary classroom, a lack of close contact with emerging knowledge a point of view consistent with assisting individuals to develop through the older curricular patterns, the grassroots type of curriculum development was slow and intermittent. Communities which developed science curriculum guides tended to follow two or three basic patterns. These in turn were not too different from basic patterns established in elementary science textbooks. Segments of subject matter were apportioned out to the several grades, either in a spiral pattern or a block-and-gap pattern, or modifications of one or the other. In the more unfortunate communities, the textbook might well have constituted the elementary science curriculum, which in turn was essentially a reading program because the teachers lacked equipment, know-how, or scientific background sufficient to involve children in science activities.

Scientists Encourage Curricular Change

In the meantime, while educators were pleading with boards of education for released teacher time to do curriculum development or to get the necessary inservice education essential to update the curriculum, scientists were developing grave concerns for the outcomes of the then extant science curricula throughout the elementary and junior high schools, in keeping with the earlier concerns for secondary school science and mathematics. Knowledge was being "produced" at a rate that made "learning the facts" an impossibility. Furthermore, scientists have long felt that the end product of science knowledge was only part of the

picture. Another significant factor was the ability to do science, to "science" as it were. Thus the emphasis, in the eyes of scientists, should swing toward the process of science and away from the facts. The end product of knowledge could not be eliminated nor should it—but the way in which one finds knowledge became as important as what was found, particularly for elementary age children. The impossibility of predicting what one might need to know in the future has led scientists and educators alike to view education as a life-long operation, and the function of formal education to provide basic learning tools to enable the learner to continue to learn for himself.

The scientists recognized some similarities between the native curiosity of the child and the intellectual quest of the scientist, however they noted that where the scientist was sophisticated in applying his disciplined mind to assist him in pursuing problems when the going got difficult, the child tended to drop his quest when his curiosity was satisfied. It was upon this need for knowing inherent in child and scientist alike, along with the realization that the knowledge of an educated person could no longer be encyclopedic, that prompted scientists to engage in curricular ventures, first at the secondary school level, and increasingly since 1960, at the elementary school level.

COMMON FEATURES OF NEW PROGRAMS

Numerous experimental programs in elementary school science have been developed. These have several features in common. In the first place all programs are *experimental*. This means that they are being tested, re-written, and tested again. In some, the testing is very rigorous, and the very nature of the program is carefully controlled. It is a tribute to educational research, and particularly curriculum research, that the testing is as rigorous as it is. Educational experimentation, in some programs, is approaching an exactitude found in the physical sciences [3]. These same experiments, as with all experiments, may prove or disprove the hypothesis being tested. This must be kept in mind. The experimental programs, as they now stand are not designed as a national curriculum in elementary science or in elementary mathematics. The manner in which the experimental curricula may influence regional and local developments will be discussed in a later section of this essay.

A second feature found in common with the experimental programs is the general emphasis on the teacher as a guide and director, rather than a font of knowledge. This role, in which the teacher sets the stage for learning ("structures the situation") may be somewhat upsetting to teachers who view science and mathematics teaching as having only one correct answer. Facts are not ends in themselves. The teacher can no longer operate in a dogmatic, "sole-source" manner in which she places greatest emphasis on "telling" children about science information.

This brings about a third similarity. This is the emphasis on process or

"scienceing" mentioned earlier. Subject matter is taken from different sources than one would previously have found in elementary science programs. For example, one might observe how insect larvae behaves under certain circumstances. It is not as important to learn specific facts about specific larvae as it is to learn how to observe, to collect data and to interpret these data [4].

A fourth similarity in the experimental programs is reflected in the importance given to the development of mathematical skills and understandings concurrently with the science. Heretofore, elementary science was not quantitative, only descriptive. As a result, some of the experimental science programs introduce advanced mathematical concepts and skills at a stage much earlier than typically experienced in the elementary school.

A fifth similarity between the experimental programs is the tendency to introduce more abstract content earlier into the program. The several programs are not uniform in any way as far as the content is concerned, yet the overall approach to content selection varies from the traditional apportionment of subject matter mentioned earlier. The experimental programs also vary from the use of the science unit typical in many elementary classrooms in which science is related to reading, social studies, arithmetic, written expression, and so forth. For example, one program utilizes the abstract idea that what one perceives is relative to the position of the perceiver in time and space.

A sixth similarity between the several programs is the emphasis on child activity. The child is not a passive listener, but instead he becomes an active participant. In many programs the activity tends to be open-ended, in that there is no one answer, nor is there a preconceived answer. In several of the programs there is no children's text. This removes the possibility of science remaining solely a "reading about science." Instead, the child must engage in activities under the guidance of the teacher. It is this role, that of the guide not the teller, that is often the most difficult for some teachers to assume. It causes one to reorient one's philosophy away from the direction-giving philosophy of teaching with the emphasis on teacher activity, toward the discovery on the part of the learner philosophy with the emphasis on learner involvement. A direct result of this approach is the disquieting fact that not everyone will arrive at the same answer, not at the same time, nor even in the same manner!

A seventh similarity between these experimental programs is the change in emphasis from science as a content subject to science as a "skill" subject as well. The skill in this case has been variously labeled critical thinking, problem-solving, discovery approach, or even creative thinking in science. This is closely related to the sixth point particularly when it comes to the implementation of this approach within a real classroom.

IMPACT OF NEW PROGRAMS

The impact of the experimental elementary science programs has begun to be felt. One outcome already apparent is the sense of respect for the specialties of the various professionals whether scientist or classroom teacher. Overheard at one recent summer writing conference was the comment made by a biologist team member concerning several elementary classroom teachers also on the team. He said, "There are some excellent elementary teachers here. They are real pros and we can be proud to work with them." The mutual respect and admiration for excellence in classroom or laboratory are bound to break down barriers in communication previously evident.

Another likely impact of these programs on the elementary school will be that teachers and school administrators will need to take time to thoroughly study the programs in depth before committing themselves to a given course. Once committed, inservice education will be needed to bring teachers into contact with the unique methodology required. A different kind of science teaching will, of necessity, emerge.

A third impact of the experimental curricula, whether these ever go beyond the testing state or not, will be the influence upon elementary science textbook materials. Some textbooks are already beginning to show evidence of the concepts and methodologies similar to those developed in experimental programs. This may be due for the most part because the science educator authors have had experience in the writing conferences. And as a result, the excitement of the curriculum experiments has been great enough to have spilled over to science educators beyond the confines of the writing teams. This in itself will be a marked impact inasmuch as the particular stimulation for a new direction has been lacking for some time in elementary science curriculum development.

The involvement of team members from several disciplines has been mentioned earlier. Cognitive psychologists and classroom teachers are sharing a new relationship involving the theoretical and the practical aspects of closely related ventures. Teachers in curriculum development have a new role, which if they become competent enough in that role to earn the respect of scientists—behavioral as well as biological and physical—they will certainly elevate themselves to a new status. Part of this new role is that of a team member who knows a great deal about the practical aspects of teaching children; who is secure enough to try new ideas that may not be her own; who is also secure enough to admit her ignorance when she does not know a fact; who is intellectually alert to devise ways of utilizing the best the new has to offer. In a sense, then, the greatest impact of experimental programs may well be felt through the

redefinition of the teacher's job beyond the telling or arbitrator stage, to a fully competent guide for learning.

References

1. See works of Gagné, Bruner, Piaget, and others.
2. Bruner, J. S., *The Process of Education*. Cambridge: Harvard University Press, 1961.
3. See both the *Commentary for Teachers* of the AAAS Science: A Process Approach and J. R. Suchman's work on inquiry training for details of experimental design and controls.
4. Education Development Center, *Elementary Science Study Sampler*, "Behavior of Mealworms."

BEHAVIORAL OBJECTIVES IN CURRICULUM DESIGN: A CAUTIONARY NOTE*

J. Myron Atkin

Dr. Atkin has several reservations about the use of behaviorally stated objectives for curriculum design. He sees the fundamental problem as being the easy assumption that we either know or can readily identify the educational objectives for which we strive and the educational outcomes that result. He believes that when any curriculum is used, there are important learning outcomes which cannot have been anticipated when the objectives were formulated. He also believes that certain types of innovation are hampered and frustrated by early demands for behavioral statements of objectives. Finally, Dr. Atkin discusses the question of priorities of objectives. He concludes that, although behavioral goals can be stated in a relatively easy fashion, they may or may not be worthwhile.

In certain influential circles, anyone who confesses to reservations about the use of behaviorally stated objectives for curriculum planning runs the risk of being labeled as the type of individual who would attack the

* REPRINTED FROM *The Science Teacher*, Vol. 35, No. 5, May 1968, pp. 27-30. Copyright, 1968, by the National Science Teachers Association, Washington, D.C. Reprinted by permission of the author and the publisher. Dr. Atkin is Associate Dean of the College of Education and also Professor of Education at the University of Illinois.

virtues of motherhood. Bumper stickers have appeared at my own institution, and probably at yours, reading, **STAMP OUT NON-BEHAVIORAL OBJECTIVES**. I trust that the person who prepared the stickers had humor as his primary aim, nevertheless, the crusade for specificity of educational outcome has become intense and evangelical. The worthiness of this particular approach has come to be accepted as self evident by ardent proponents, proponents who sometimes sound like the true believers who cluster about a new social or religious movement.

Behavioral objectives enthusiasts are warmly endorsed and embraced by the systems and operations analysis advocates, most educational technologists, the cost-benefit economists, the planning-programming budgeting system stylists, and many others. In fact, the behavioral objectives people are now near the center of curriculum decision making. Make no mistake, they have replaced the academicians and the general curriculum theorists—especially in the new electronically based education industries and in governmental planning agencies. The engineering model for educational research and development represents a forceful tide today. Those who have a few doubts about the effects of the tide had better be prepared to be considered uninitiated and naive, if not slightly addled and antiquarian.

To utilize the techniques for long-term planning and rational decision making that have been developed with such apparent success in the Department of Defense, and that are now being applied to a range of domestic and civilian problems, it is essential that hard data be secured. Otherwise these modes for developmental work and planning are severely limited. Fuzzy and tentative statements of possible achievement and questions of conflict with respect to underlying values are not compatible with the new instructional systems management approaches—at least not with the present state of the art. In fact, delineating instructional objectives in terms of identifiable pupil behaviors or performances seems essential in 1968 for assessing the output of the educational system. Currently accepted wisdom does not seem to admit an alternative.

There are overwhelmingly useful purposes served by attempting to identify educational goals in non-ambiguous terms. To plan rationally for a growing educational system, and to continue to justify relatively high public expenditures for education, it seems that we do need a firmer basis for making assessments and decisions than now exists. Current attention to specification of curriculum objectives in terms of pupil performance represents an attempt to provide direction for collection of data that will result in more informed choice among competing alternatives.

Efforts to identify educational outcomes in behavioral terms also provide a fertile ground for coping with interesting research problems and challenging technical puzzles. A world of educational research opens to the investigator when he has reliable measures of educational output (even when their validity for educational purposes is low). Pressures from

researchers are difficult to resist since they do carry influence in the educational community, particularly in academic settings and in educational development laboratories.

Hence I am not unmindful of some of the possible benefits to be derived from attempts to rationalize our decision-making processes through the use of behaviorally stated objectives. Schools need a basis for informed choice. And the care and feeding of educational researchers is a central part of my job at Illinois. However, many of the enthusiasts have given insufficient attention to underlying assumptions and broad questions of educational policy. I intend in this brief paper to highlight a few of these issues in the hope that the exercise might be productive of further and deeper discussion.

Several reservations about the use of behaviorally stated objectives for curriculum design will be catalogued here. But perhaps the fundamental problem, as I see it, lies in the easy assumption that we either know or can readily identify the educational objectives for which we strive, and thereafter the educational outcomes that result from our programs. One contention basic to my argument is that we presently are making progress toward thousands of goals in any existing educational program, progress of which we are perhaps dimly aware, can articulate only with great difficulty, and that contribute toward goals which are incompletely stated (or unrecognized), but which are often worthy.

For example, a child who is learning about mealworm behavior by blowing against the animal through a straw is probably learning much more than how this insect responds to a gentle stream of warm air. Let's assume for the moment that we can specify "behaviorally" all that he might learn about mealworm *behavior* (an arduous and never-ending task). In addition, in this "simple" activity, he is probably finding out something about interaction of objects, forces, humane treatment of animals, his own ability to manipulate the environment, structural characteristics of the larval form of certain insects, equilibrium, the results of doing an experiment at the suggestion of the teacher, the rewards of independent experimentation, the judgment of the curriculum developers in suggesting that children engage in such an exercise, possible uses of a plastic straw, and the length of time for which one individual might be engaged in a learning activity and still display a high degree of interest. I am sure there are many additional learnings, literally too numerous to mention in fewer than eight or ten pages. When any piece of curriculum is used with real people, there are important learning outcomes that cannot have been anticipated when the objectives were formulated. And of the relatively few outcomes that can be identified at all, a smaller number still are translatable readily in terms of student behavior. There is a possibility the cumulative side effects are at least as important as the intended main effects.

Multiply learning outcomes from the mealworm activity by all the

various curriculum elements we attempt to build into a school day. Then multiply this by the number of days in a school year, and you have some indication of the oversimplification that *always* occurs when curriculum intents or outcomes are articulated in any form that is considered manageable.

If my argument has validity to this point, the possible implications are potentially dangerous. If identification of all worthwhile outcomes in behavioral terms comes to be commonly accepted and expected, then it is inevitable that, over time, the curriculum will tend to emphasize those elements which have been thus identified. Important outcomes which are detected only with great difficulty and which are translated only rarely into behavioral terms tend to atrophy. They disappear from the curriculum because we spend all the time allotted to us in teaching explicitly for the more readily specifiable learnings to which we have been directed.

We have a rough analogy in the use of tests. Prestigious examinations that are widely accepted and broadly used, such as the New York State Regents examinations, tend over time to determine the curriculum. Whether or not these examinations indeed measure all outcomes that are worth achieving, the curriculum regresses toward the objectives reflected by the test items. Delineation of lists of behavioral objectives, like broadly used testing programs, may admirably serve the educational researcher because it gives him indices of gross achievement as well as detail of particular achievement; it may also provide input for cost-benefit analysts and governmental planners at all levels because it gives them hard data with which to work; but the program in the schools may be affected detrimentally by the gradual disappearance of worthwhile learning activities for which we have not succeeded in establishing a one-to-one correspondence between curriculum elements and rather difficult-to-measure educational results.

Among the learning activities most readily lost are those that are long term and private in effect and those for which a single course provides only a small increment. If even that increment cannot be identified, it tends to lose out in the teacher's priority scheme, because it is competing with other objectives which have been elaborately stated and to which he has been alerted. But I will get to the question of priority of objectives a bit later.

The second point I would like to develop relates to the effect of demands for behavioral specification on innovation. My claim here is that certain types of innovation, highly desirable ones, are hampered and frustrated by early demands for behavioral statements of objectives.

Let's focus on the curriculum reform movement of the past 15 years, the movement initiated by Max Beberman in 1952 when he began to design a mathematics program in order that the high school curriculum would reflect concepts central to modern mathematics. We have now seen

curriculum development efforts, with this basic flavor, in many science fields, the social sciences, English, esthetics, etc. When one talks with the initiators of such projects, particularly at the beginning of their efforts, one finds that they do not begin by talking about the manner in which they would like to change pupils' behavior. Rather they are dissatisfied with existing curricula in their respective subject fields, and they want to build something new. If pressed, they might indicate that existing programs stress concepts considered trivial by those who practice the discipline. They might also say that the curriculum poorly reflects styles of intellectual inquiry in the various fields. Press them further, and they might say that they want to build a new program that more accurately displays the "essence" of history, or physics, or economics, or whatever. Or a program that better transmits a comprehension of the elaborate and elegant interconnections among various concepts within the discipline.

If they are asked at an early stage just how they want pupils to behave differently, they are likely to look quite blank. Academicians in the various cognate fields do not speak the language of short-term or long-term behavioral change, as do many psychologists. In fact, if a hard-driving behaviorist attempts to force the issue and succeeds, one finds that the disciplinarians can come up with a list of behavioral goals that looks like a caricature of the subject field in question. (Witness the AAAS elementary-school science program directed toward teaching "process.")

Further, early articulation of behavioral objectives by the curriculum developer inevitably tends to limit the range of his exploration. He becomes committed to designing programs that achieve these goals. Thus if specific objectives in behavioral terms are identified early, there tends to be a limiting element built into the new curriculum. The innovator is less alert to potentially productive tangents.

The effective curriculum developer typically begins with *general* objectives. He then refines the program through a series of successive approximations. He doesn't start with a blueprint, and he isn't in much of a hurry to get his ideas represented by a blueprint.

A situation is created in the newer curriculum design procedures based on behaviorally stated objectives in which scholars who do not talk a behavioral-change language are expected to describe their goals at a time when the intricate intellectual subtleties of their work may not be clear, even in the disciplinary language with which they are familiar. At the other end, the educational evaluator, the behavioral specifier, typically has very little understanding of the curriculum that is being designed—understanding with respect to the new view of the subject field that it affords. It is too much to expect that the behavioral analyst, or anyone else, recognize the shadings of meaning in various evolving economic theories, the complex applications of the intricacies of wave motion, or the richness of nuance reflected in a Stravinsky composition.

Yet despite this two-culture problem—finding a match between the behavioral analysts and the disciplinary scholars—we still find that an expectation is being created for early behavioral identification of essential outcomes.

(Individuals who are concerned with producing hard data reflecting educational outputs would run less risk of dampening innovation if they were to enter the curriculum development scene in a more unobtrusive fashion—and later—than is sometimes the case. The curriculum developer goes into the classroom with only a poorly articulated view of the changes he wants to make. Then he begins working with children to see what he can do. He revises. He develops new ideas. He continually modifies as he develops. *After* he has produced a program that seems pleasing, it might then be a productive exercise for the behavioral analyst to attempt with the curriculum developer to identify *some* of the ways in which children seem to be behaving differently. If this approach is taken, I would caution, however, that observers be alert for long-term as well as short-term effects, subtle as well as obvious inputs.)

A third basic point to be emphasized relates to the question of instructional priorities, mentioned earlier. I think I have indicated that there is a vast library of goals that represent possible outcomes for any instructional program. A key educational task, and a task that is well handled by the effective teacher, is that of relating educational goals to the situation at hand—as well as relating the situation at hand to educational goals. It is impractical to pursue all goals thoroughly. And it does make a difference *when* you try to teach something. Considerable educational potential is lost when certain concepts are taught didactically. Let's assume that some third-grade teacher considers it important to develop concepts related to sportsmanship. It would be a rather naive teacher who decided that she would undertake this task at 1:40 PM on Friday of next week. The experienced teacher has always realized that learnings related to such an area must be stressed in an appropriate context, and the context often cannot be planned.

Perhaps there is no problem in accepting this view with respect to a concept like sportsmanship, but I submit that a similar case can be made for a range of crucial cognitive outcomes that are basic to various subject-matter fields. I use science for my examples because I know more about this field than about others. But equilibrium, successive approximation, symmetry, entropy, and conservation are pervasive ideas with a broad range of application. These ideas are taught with the richest meaning only when they are emphasized repeatedly in appropriate and varied contexts. Many of these contexts arise in classroom situations that are unplanned, but that have powerful potential. It is detrimental to learning not to capitalize on the opportune moments for effectively teaching one idea or another. Riveting the teacher's attention to a few behavioral goals provides him with blinders that may limit his range.

Directing him to hundreds of goals leads to confusing, mechanical pedagogic style and loss of spontaneity.

A final point to be made in this paper relates to values, and it deals with a primary flaw in the consumption of much educational research. It is difficult to resist the assumption that those attributes which we can measure are the elements which we consider most important. This point relates to my first, but I feel that it is essential to emphasize the problem. The behavioral analyst seems to assume that for an objective to be worthwhile, we must have methods of observing progress. But worthwhile goals come first, not our methods for assessing progress toward these goals. Goals are derived from our needs and from our philosophies. They are not and should not be derived primarily from our measures. It borders on the irresponsible for those who exhort us to state objectives in behavioral terms to avoid the issue of determining worth. Inevitably there is an implication of worth behind any act of measurement. What the educational community poorly realizes at the moment is that behavioral goals may or may not be worthwhile. They are articulated from among the vast library of goals because they are stated relatively easily. Again, let's not assume that what we can presently measure necessarily represents our most important activity.

I hope that in this paper I have increased rather than decreased the possibilities for constructive discourse about the use of behavioral objectives for curriculum design. The issues here represent a few of the basic questions that seem crucial enough to be examined in an open forum that admits the possibility of fresh perspectives. Too much of the debate related to the use of behavioral objectives has been conducted in an argumentative style that characterizes discussions of fundamental religious views among adherents who are poorly informed. A constructive effort might be centered on identification of those issues which seem to be amenable to resolution by empirical means and those which do not. At any rate, I feel confident that efforts of the next few years will better inform us about the positive as well as negative potential inherent in a view of curriculum design that places the identification of behavioral objectives at the core.

EVALUATING NEW PROGRAMS IN ELEMENTARY SCIENCE*

Alphoretta S. Fish

Alphoretta S. Fish cautions against the use of teachers as mere adjuncts to the materials they teach when new programs are instituted. Dr. Fish considers it imperative that teachers play a more prominent role in the (1) examination of the system within which programs are conceived, (2) evaluation of the relationships between goals and methods, and (3) reconstruction of the program.

There is much competition at this time to describe and prescribe for science instruction at the elementary school level. Scientists, psychologists, and educators are making concerted efforts to develop various curricula. Since scientists, psychologists, and educators represent different frames of reference, widely divergent kinds of curriculum designs are emerging. For example, there is a notion, on the one hand, that any effort to guide pupils to develop an understanding of the processes of inquiry should not be undertaken at the elementary school level. The psychologist, Gagné,¹ has stated:

There is nothing wrong with practicing enquiry, and surely enquiry is the kind of capability we want students of science to attain in some terminal sense. But practicing enquiry too soon, and without a suitable background of knowledge, can have a narrowing and cramping effect on the individual's development of independent thinking.

On the other hand is the conviction that an important function of elementary school science instruction is to develop both the skills and understandings attending inquiry. Suchman² has stated his rationale as follows:

* REPRINTED FROM *School Science and Mathematics*, Vol. 65, No. 6, June 1965, pp. 531-533, by permission of the author and the publisher. Dr. Fish is Associate Professor of Education, University of Saskatchewan, Canada.

¹ Gagné, Robert M. "The Learning Requirements for Enquiry," *Journal of Research in Science Teaching*, 1 (1963), 147.

² Suchman, J. Richard, *The Elementary School Program in Scientific Inquiry*. Urbana, Illinois: University of Illinois, 1962.

a. Learning through inquiry transcends learning which is directed wholly by the teacher or the textbook; the autonomous inquirer assimilates his experience more independently. He is free to pursue knowledge and understanding in accordance with his cognitive needs and his individual level and rate of assimilation.

b. Inquiry is highly motivated because children enjoy autonomous activity particularly when it produces conceptual growth.

c. Concepts that result from inquiry are likely to have greater significance to the child because they have come from his own acts of searching and data processing. They are formed by the learner himself from the data he has collected and processed himself; and for that reason should be more meaningful to him, and hence more stable and functional.

Obviously, curricula resulting from such opposing viewpoints are bound to be quite different. Who then is to make judgments and select from among alternative curricula?

THE FRAME OF REFERENCE FOR EVALUATION

As a matter of fact, the first order of business once a new program has been conceived and developed is to have classroom teachers test it. Unfortunately, classroom teachers too often are introduced to the means—that is, the materials and activities—of the program and to the stated goals, or the end-in-view, of the program without being thoroughly grounded in what Walbesser calls “the character of what is to be learned.”³ Walbesser, who is in charge of the evaluation study of the new curriculum materials for elementary school science being developed by the Commission on Science Education of AAAS, has stated:

If any hope of success for a given set of activities is to be sustained, then the individuals attempting to use the materials must know the character of what is to be learned.⁴

The character of what is to be learned is to be located in the system within which it was conceived and cannot be discerned from the materials alone. As a matter of fact, teachers are more than mere adjuncts to the materials they teach; and little that is significant can be determined about the effectiveness of a curriculum by merely providing opportunity for teachers to “live through” a set of activities with a group of pupils.

CRITERIA FOR SELECTING CURRICULUM

Selection of a curriculum should be based on a set of criteria for judging

³ Walbesser, Henry H., “Curriculum Evaluation by Means of Behavioral Objectives,” *Journal of Research in Science*, I (1963), 297.

⁴ *Loc. cit.*

that is consistent with the philosophy underlying the curriculum. Otherwise, inconsistencies exist between the criteria for judging valued by the teachers and the criteria for judging valued by the curriculum designers. For example, one of the criteria often valued by teachers with regard to new curriculum designs is: Is it different from what I do regularly? Comments such as, "These are the same kinds of activities we do in arithmetic," represent the teacher's lack of understanding of how the materials, the objectives, and the methods are related. Such comments may indicate also that teachers fail to recognize the importance of being involved in the evaluation of the new curriculum.

To effectively judge a new curriculum, teachers must be encouraged to inquire into the very system in which the rationale of the curriculum is grounded. Initially, teachers should be concerned with:

1. The stated goals of the curriculum and should inquire: Are these the goals we want?
2. The means for achieving the goals and should inquire: Are the means selected appropriate to reach the goals?
3. The methods for achieving the goals and should inquire: Are the methods consistent with the stated goals?

Hence it is that materials and methods are judged according to their relevancy to the desired outcomes.

CONSISTENCY OF EVALUATIVE MEASURES

Another, even more crucial concern in judging the consistency of new curricula should be the validity of the methods to be employed in the programs for evaluating the stated goals. This concern should lead the teacher to inquire: Are the means and methods of evaluating the program consistent with the stated goals? The practice of using evaluative instruments which are subject matter oriented to judge goals stated in behavioral terms cannot be defended on the basis that the results are more easily quantified. For example, any new curriculum which purports to develop behavioral outcomes which in any way reflect inquiry should have an evaluative instrument designed *not to test subject matter and manipulative skill competencies* but to answer such questions as:

1. As a result of the new curriculum design, do pupils who formerly asked questions only about subject matter now ask questions about the processes as well?
2. As a result of the new curriculum design, do pupils who formerly failed to question science meanings now build criteria for examining and judging meanings and demand precision in language, logic in argument, and responsibility in judgment making?

ROLE OF THE TEACHER IN CURRICULUM DESIGN

It seems reasonable to suggest, at this point, that in order to judge a new curriculum effectively, teachers should be provided with ample opportunity to inquire into the relationships among the activities, the goals, and the methods in order to develop an understanding of the system within which the program was conceived. It is not enough that curriculum designers state in the preface of a curriculum guide that the activities contained therein promote particular behaviors. For as long as the question, "How do these means promote these ends?" remains unanswered in the mind of the teacher, she cannot even be expected to perceive the relationships between the activities to be tested and the behaviors which supposedly will be evoked. With the question unanswered, neither can the teacher be expected to transmit the significance of the activities of the pupil.

Therefore, if the practice of asking teachers to "test" new curricula is to be continued, it would seem to be imperative that teachers play a more prominent role in the (1) examination of the system within which the programs are conceived, (2) evaluation of the relationships between goals and method, and (3) reconstruction of the program.

SCIENCE IN THE ELEMENTARY SCHOOL: A LOOK AHEAD*

Katherine E. Hill

After a brief look at the present climate for elementary science, Dr. Hill attempts to predict the future status of science in the elementary school. She believes that new science programs will increasingly take into consideration the nature of the children themselves. Individualization of instruction will become a primary concern. This concern will result in different kinds of evaluation, a change in the design of school buildings, different kinds and uses of text and reference books, a multi-media approach to science teaching, a K-12 science program, and the increased use of science consultants and of trained science teaching specialists.

* REPRINTED FROM *Science and Children*, Vol. 6, No. 5, January-February 1969, pp. 28-33. Copyright, 1969, by the National Science Teachers Association, Washington, D.C. Reprinted by permission of the author and the publisher. Dr. Hill is Professor of Education at New York University.

Predictions and questions related to the future of teaching science to children must have their roots in past developments concerning not only instruction and learning in science but instruction and learning in general. Even more, these predictions and questions must stem from what is known about children as they live and grow in this society at this time and from what society appears to foresee as the future.

Admittedly, these are issues which defy complete analysis and to which there can be no final answers, yet they must be faced if progress in science instruction is to be made. The National Science Teachers Association, hand-in-hand with other professional groups, has provided leadership in attempting to resolve some of these issues and must provide even more in the years to come through the active participation of its membership.

THE PRESENT CLIMATE FOR ELEMENTARY-SCHOOL SCIENCE

At the moment, educators probably are in the most enviable position they have ever known as far as public commitment to public education and as far as research in teaching and learning are concerned. The public commitment to education is evident by the funds made available by national, state, and local legislative bodies. It is evident also in public discussion of education issues in magazines, newspapers, books, and on radio and television programs, not to mention conversations in innumerable living rooms and over countless dinner tables.

In reviewing such evidence of the public's concern with the education of its children, it would be difficult to find a slighting of the importance of instruction in science. Science is no longer viewed as a frill or merely as a *possible* component of curriculum provided there is time for it. Rather, it is *in* the curriculum of the elementary school, and it is there to stay. This statement could not have been made with conviction twenty years ago, or even ten years ago, for the general concern about and acceptance of the necessity for instruction in science for children is a product of the post World War II years.

However, by 1963, the public's concern with regard to early instruction in science was apparent to the National Science Teachers Association and to the Department of Elementary School Principals. In that year, these organizations recognized the importance of communicating with parents concerning science by publishing *You & Your Child & Science*.¹

Because the onset of this general concern has been swift, many educators in many school systems have felt somewhat at sea as to the capacities of children for learning science, the goals for science instruction, the relationship of science to other curriculum areas and to

¹ Blough, Glenn O. *You & Your Child & Science*. National Education Association, Washington, D.C. 1963.

other levels of instruction, the environment for learning in science, and the personnel best suited to give instruction in science.

Today, there is opportunity to use a vast amount of accumulated evidence concerning learning as educators move forward toward the solution of such problems. For example, more general use is being made of certain research-backed theories proposed years ago, theories like this one which Dewey published in 1937:

I use the word "understanding" rather than knowledge because unfortunately, knowledge to so many people means "information." Information is knowledge about things, and there is no guarantee in any amount of "knowledge about things" that understanding—the spring of intelligent action—will follow from it. . . . Understanding has to be in terms of how things work and how to do things. Understanding, by its very nature, is related to action; just as information, by its very nature, is isolated from action or connected with it only here and there by accident.²

Or this theory of Kilpatrick's: "We learn what we live, we learn each item we live as we accept it, and we learn it in the degree we accept it."³

Those presently engaged in learning theory are putting more meat on the skeleton constructed by earlier educators. The theories of Bruner, Piaget, Taba, and others bear out the point that children *do* learn that which they experience at first hand. Thus, present-day learning theorists propose that children work, under guidance, in environments which encourage active involvement with others in testing ideas.

For many years, advocacy of this general theory of the necessity of active involvement if learning is to occur has been the position of some science educators. In 1937, Craig stated his position in this way:

Teaching science in the elementary school is not a mere matter of the presentation of the content in science. Some of the phases of instruction that may be shared with children are: proposing problems, defining problems, suggesting methods for solution of problems, relating experiences to the solution of a problem, suggesting observation that may be made, thinking through the problem, suggesting an experiment that may be made to solve the problem, assisting in drawing conclusions, assisting with experiments . . . questioning superstitions, myths and unscientific material, discarding opinions, and recognizing the difference between the solution proposed by class members and scientific information.⁴

This position has long been that of NSTA as well. In May 1958, the Association convened a group of some 30 educators in Washington to

² Dewey, John. "The Challenge of Democracy to Education." *Progressive Education* XIV, No. 2. February 1937.

³ Kilpatrick, William H. *Philosophy of Education*. The Macmillan Company, New York. 1951. p. 244.

⁴ Craig, Gerald S. "Science and Elementary Education." *Teachers College Record* XXXVIII, No. 8. May 1937. pp. 660-677.

consider means by which elementary-school science might be strengthened. The report of this conference included this statement:

Through the study of science, pupils build concepts and ideas of their world which they use in interpreting it. It is through an accumulation of concepts that they learn to understand what is happening around them and why it happens and consequently they are able to react more intelligently. It is through this process that they become better prepared to live in today's world.

Problem-solving in science involves the use of scientific habits and attitudes which include: careful observation, accurate interpretation of these observations, and skillful recording and communicating of them. It includes the habit of withholding judgment, questioning sources of information, consulting many sources, and other similar aspects of what is commonly called scientific attitude. Children are led to see the cause and effect relationships in science as they proceed in its study. In turn, application of this knowledge may be used to solve their own problems.⁵

It is heartening to note that recent courses of study, textbook series, and funded curriculum projects are making fuller and fuller use of these principles for instruction in science. As a matter of fact, in the past few years, hours of discussion and hundreds of written words have been devoted to a consideration of process vs. content in elementary science with the result, apparently, that there is a consensus of opinion that one cannot exist without the other. Although it probably would be impossible to find a published elementary school science program which might be termed a reading-about-science program, unfortunately classrooms still exist in which children are not actively involved with science as part of their in-school lives.

Just as there seems to be general agreement about the necessity of active involvement of children in science experiences, there seems to be general agreement concerning the content that should be included. Today, it would be difficult to find an educator who advocates that children, ages 5 to 12, should be limited to investigations of biological phenomena principally. Yet this once was the case when nature study was the basis for all science study. By and large, there appears to be agreement that there should be no restriction as to science content other than whether or not the children concerned have had enough experience, have developed sufficient study skills, and have reached a level of maturity necessary for dealing with the content. This observation will be borne out by examining any of the present courses of study, textbook series, or funded projects.

A rationale for organizing content in elementary school science has been evolving for some time. Some years ago Craig suggested that content be selected to build children's understanding of certain basic, working conceptions in science which he termed large patterns of the universe. More recently, he has revised these patterns and stated them in this

⁵ Blough, Glenn O. *It's Time for Better Elementary School Science*. National Science Teachers Association, Washington, D.C. 1958. pp. 5-6.

manner: The universe is large; Earth is very old; energy is involved in all motion and change; life is adapted to the environment; there are great variations in the universe; the interdependence of living things; and the interaction of forces.⁶

The National Science Teachers Association, through its officers, committees, and general membership, explored for some five years in the late fifties and early sixties its beliefs concerning the organization of the science curriculum, K-12. Advocacy of the use of conceptual schemes and major items in the process of science as criteria for planning sequential courses and for selecting content was the outcome. Certain broad principles which can be brought to bear on curriculum construction at all levels of instruction are delineated in *Theory Into Action in Science Curriculum Development*,⁷ the report of the NSTA Curriculum Committee and the NSTA Conference of Scientists. The first of seven conceptual schemes proposed in this publication is "All matter is composed of units called fundamental particles; under certain conditions these particles can be transformed into energy and vice versa." The first of five major items of process which were identified is "Science proceeds on the assumption, based on centuries of experience, that the universe is not capricious."

It is interesting to note that the content presented in several recent textbook series for grades 1-6 has been selected using such patterns or conceptual schemes as criteria, and at least one funded project uses this rationale in the development of a science curriculum for children.⁸

Because many agree that science in the elementary school should focus on the processes of science and make use of basic patterns or conceptual schemes in selecting content, a knotty problem emerges. This concerns personnel charged with instruction in science. Under present certification laws, classroom teachers are well qualified in child development information, learning theories, and techniques of working with children. However, usually these teachers are required to have no more than six college semester hours in biological sciences, six in physical sciences, and two in the teaching of science in the elementary school. Further, the requirement in mathematics is, at the most, six semester hours. Although electives in the natural sciences and in mathematics are possible in most programs, few teachers choose them. Informal discussion with senior college students indicates that they do not choose to take electives in these disciplines because of dislike for them and fear of failure. The

⁶ Craig, Gerald S. *Science for the Elementary School Teacher*. Blaisdell Publishing Company, Waltham, Massachusetts, 1966, pp. 92-100.

⁷ NSTA Curriculum Committee and the Conference on Science Concepts. *Theory Into Action in Science Curriculum Development*. National Science Teachers Association, Washington, D.C. 1964.

⁸ COPES (Conceptually Oriented Program in Elementary Science). *The Teacher's Guide for a Conservation of Energy Sequence*. New York University, New York. 1967.

problem, then, is concerned with who shall teach the children involved in today's relatively sophisticated programs in science.

Perhaps a brief pause is in order to focus on the present state of affairs as far as instruction in science in the elementary school is concerned. It appears that one could say that the climate for science is positive, that there is rather general agreement as to theory of instruction and basis for selection of content in science, and that the most pressing problem to be faced is the securing of persons with sufficient science backgrounds and who, at the same time, are highly skilled in working with children.

THE FUTURE STATUS OF SCIENCE IN THE ELEMENTARY SCHOOL

Predicting the future is always risky. Nevertheless, I should like to attempt some crystal-ball gazing.

First, the nature of the children themselves will more and more be taken into consideration as science programs are planned and executed. A great deal more is known about the growth and development of children than most schools are using in the teacher-learning process. However, there is abundant evidence that increasing attention is being given to the fact that each child matures at his own rate, although children of any one age level possess certain broad characteristics in common.

For example, individualization of instruction is becoming a primary concern in all areas of curriculum, including science. NSTA is one of the groups which has indicated its concern about this matter by publishing *How To Individualize Science Instruction*.⁹ Courses of study and textbook series are suggesting a wealth of in-depth study for the more capable and many extending experiences for the less capable.

Recently, Sullivan and Taylor¹⁰ have called attention to the importance of the creativity factor in learning science. Also, the findings of Getzels and Jackson¹¹ indicate that creative thinking, a prime factor in science study, is not synonymous with intelligent thinking as measured by the IQ. Since IQ, especially at upper grade levels, is closely associated with ability to read, there is reason to believe that grouping for individualized instruction in science should not be based upon a procedure which uses reading ability as a criterion. As a matter of fact, this author's experience has been that in certain instances where science instruction has been carried on without having children read (and please note that it is not

⁹ Munch, Theodore W. *How to Individualize Science Instruction in the Elementary School*. National Science Teachers Association, Washington, D.C. 1965.

¹⁰ Sullivan, John J., and Taylor, Calvin W. *Learning and Creativity, With Special Emphasis on Science*. National Science Teachers Association, Washington, D.C. 1967.

¹¹ Getzels, Jacob W., and Jackson, Philip W. *Creativity and Intelligence*. John Wiley & Sons, Inc., New York. 1962.

advocated that such always be the case), it has been impossible to determine the reading ability of children on the basis of their ability to grapple with concepts in science.

Such findings suggest that in science instruction, at least, there need be no undue concern for the socioeconomic backgrounds of children, despite the fact that reading ability and socioeconomic background have a high degree of positive correlation. Children of all backgrounds are confronted with common natural phenomena such as rain, the sun, animals, plants, electricity, and so on. All have questions about such phenomena and experiences with them. All have the ability to think about them, but within each socioeconomic level there will be some children who are less capable and some who are more capable than others. Indeed, at least one prominent science educator has suggested¹² that science be the major content core of the elementary-school curriculum since a child's socioeconomic status appears not to influence his ability to achieve in this area.

Another evidence of the growing concern for individualization of instruction in science is dissatisfaction with attempts to evaluate the progress of children by relying solely on informal methods, such as group discussions. Present rationale is that every effort must be made to assess the concept development of each individual at certain points if instruction is to be designed for that individual. That attention is being focused on this problem is evidenced by such publications as NSTA's *Improving Objective Tests in Science*¹³ and new types of tests resulting from funded projects such as COPEs¹⁴ and the AAAS *Science—A Process Approach*.¹⁵

Still further evidence of the increasing concern regarding individualization of instruction, including instruction in science, is the design of school buildings themselves and the consequent restructuring of ways of working with children. Schools are being built, not with individual classrooms, but with several large, open areas, each area housing a group of 150 or so children. Movable walls within the large areas may be used to create smaller spaces as needed. The children thus housed need not be third-graders nor sixth-graders; rather, each large group may be composed of children who might usually be classified as first-, second-, and third-graders or as fourth-, fifth-, and sixth-graders. It is obvious that in such a situation, it would be possible to group children in many different

¹² Shamos, Morris H., 1967-68 NSTA President and Chairman of the Department of Physics, New York University, in personal communication.

¹³ Nelson, Clarence H. *Improving Objective Tests in Science*. National Science Teachers Association, Washington, D.C. 1967.

¹⁴ U.S. Department of Health, Education, and Welfare, Final Report, Project No. H281, *A Pilot Project to Develop an Elementary Science Sequence*. New York University, New York. 1967.

¹⁵ Commission on Science Education. *Science—A Process Approach*. American Association for the Advancement of Science, Washington, D.C. 1965 and 1966.

ways in order to provide for optimum learning on the part of each individual.

As such innovations in housing and grouping become more widespread, it seems safe to predict that *the* textbook for a particular grade or *the* course of study will no longer be feasible. It will become imperative that opportunities be available for individual and small-group exploration in science. The science curriculum can no longer be envisioned in the traditional, tri-sectional package of elementary, junior high, and senior high school. Total programs for K-12 and beyond must be developed. And, at the moment, it appears that the guidelines for selection of content and experiences should be certain universal patterns or conceptual schemes which thread through all the natural sciences. The National Science Teachers Association's suggestions concerning such guidelines were set forth in *New Developments in Elementary School Science* as follows:

For the elementary school, as well as for all other levels of education, the objectives of science instruction center around growth in understanding of science concepts and in ability to participate in the process of scientific inquiry.¹⁶

Surely, a multi-media approach to science instruction will be increasingly necessary. Books there will be, many books on many different subjects for many different reading levels. In addition, film loops, filmstrips, tapes, videotapes, excursions, displays, still pictures, programed written sequences, and other such aids will be available in as great diversity as has been indicated for books. Computer-assisted instruction in science will be increasingly possible for children in even the most isolated of schools.

It is entirely possible, then, that better programs and better materials for instruction in elementary-school science are already in sight. But the knotty problem suggested earlier persists. Who will be able to do the kind of instruction in science which will be imperative if optimum values are to be realized? It becomes increasingly apparent that an elementary school teacher, isolated in his own classroom, will seldom be able to do the job alone. But he will continue to be the basic factor—the steady and steady influence—in the teaching-learning situation, for he is the one who will know most about the children in his charge.

In order to assist this teacher in his work, more than buildings and materials must be available. There must be help in human form. In some schools, team teaching may solve the problem as far as science instruction is concerned, but even more promising appears to be the use of consultants and of special teachers. In a consultant program, all classroom teachers will have as much assistance as is needed from the consultant, a person who has a broad science background, who is capable of assisting in

¹⁶ Zaffaroni, Joseph, and Selberg, Edith, *New Developments in Elementary School Science*. National Science Teachers Association, Washington, D.C. 1963.

the teaching of both groups and individuals, who maintains a science laboratory for the use of both individuals and groups, who is responsible for appraising new materials as they appear and making them available to the classroom teacher, and who can provide leadership in articulating the elementary-school portion of the K-12 science program. In the so-called special-teacher programs, all science instruction will be done by a person especially trained for such teaching. However, until such time as research indicates otherwise, it seems that at least through the third grade, instruction in all curriculum areas should be in the hands of a classroom teacher who has the unfailing assistance of a consultant. Beyond this point, it may be possible that the science instruction should be in the hands of a special teacher, a highly qualified, elementary-science specialist.

Certainly, it is not only hoped but confidently expected that the National Science Teachers Association will continue to encourage discussion on issues such as these and will take definite positions when appropriate.

Thus far, this analysis indicates innovations which are even now in the process of implementation, innovations which it is believed will result in a far more scientifically literate population. The National Science Teachers Association has played a major role in suggesting innovations and methods of implementing the innovations. That this has been and continues to be the case is abundantly evident in its annual national and regional conferences, in articles in *Science and Children*,¹⁷ and in many of its other publications.

But is scientific literacy enough? There seems to be an uneasy stirring in the science education community concerning a further commitment to children and youth, a commitment that is not new. Indeed, this commitment to those ultimately responsible for our society appeared at least as early as 1932.¹⁸ It involves children and science *in* our society. Perhaps the problem was as well stated by Dewey as anyone when he wrote:

Unless our schools take science in its relation to the understanding of those forces which are now shaping society, and, still more, how the resources of the organized intelligence that is science might be used in organized social action, the outlook for democracy is insecure.¹⁹

¹⁷ *Science and Children*. Published eight times each year. National Science Teachers Association, Washington, D.C.

¹⁸ National Society for the Study of Education. *A Program for Teaching Science—Thirty-first Yearbook of the National Society for the Study of Education, Part 1*. University of Chicago Press, Chicago, Illinois. 1932.

¹⁹ Dewey, John. "The Challenge of Democracy to Education,," *Progressive Education* XIV, No. 2. February 1937.

To be sure, there is some forward motion in this direction. For example, conservation of plant and animal life and the problems of air and water pollution are written into some science programs, but there undoubtedly is something even more fundamental for science instruction if science *and* society are considered fully. No one knows what the next thrust will be in science teaching at the elementary school level, but today's national and world climates suggest that this thrust must be in the realm of the interrelationship of science and social action and the work must be started at once.



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